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# Report

## Climate change 2020 - 2050

Consequences for the NordPool electricity market

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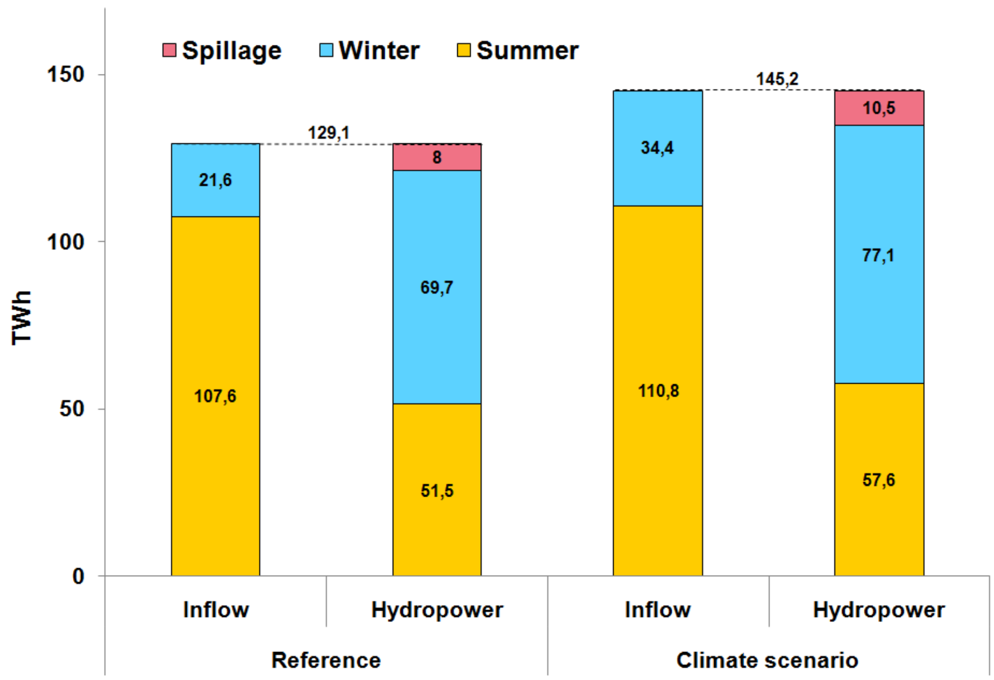


**Effects for Norwegian hydropower**

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Energy Systems
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**ABSTRACT**

### Abstract heading

The objective of this study is to analyze the Nordic power market under changing climate conditions. A different climate affects the power market mainly through changes in inflow and temperatures. We use the EMPS-model to simulate the 2020-system, using expected values for demand, supply and transmission. The reference climate scenario is based on observed climatic variables from the period 1961 to 1990. The alternative climate scenarios are for the period 2021 – 2050, and are based on the climate models "met.no-HIRHAM-HadCM3-A1B" and "DMI-HIRHAM-Echam5-A1B".

In the two future climate scenarios, the simulated hydropower production increases by approximately 10 % for the whole NordPool area compared to the reference climate. The simulated reservoir level has less variation over the year, mainly because of larger inflow during the winter. The probability of energy shortage is reduced, while the average spillage from reservoirs is increased. Average prices for electricity are reduced for every week.

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## Executive summary


**Introduction**
The objective of this study is to analyze the Nordic power market under changing climate conditions. The analysis is based on an assumed 2020 system configuration that is simulated with three different climate scenarios (i.e. hydro inflow and temperature). The reference climate scenario is based on observed climatic variables from the period 1961 to 1990, whereas the remaining two scenarios are forecasted climatic variables, provided by project partners from models "met.no-HIRHAM-HadCM3-A1B" and "DMI-HIRHAM-Echam5-A1B", for the period 2021 to 2050. The simulation results show how demand, generation and transmission change, for a fixed system configuration, when climatic conditions are altered.

**Methodology**
The system simulations are carried out using the EMPS-model (Wolfgang, Haugstad, Mo, Gjelsvik, Wangensteen, & Doorman, Hydro reservoir handling in Norway before and after deregulation, 2009). EMPS simulates the optimal operation of the Nordic system and the interconnection to continental Europe. Simulations give detailed results for power production for different technologies, demand, prices and exchange between the Nordic areas and with the connected European countries.

Recently, automatic calibration has been introduced in the EMPS-model, reducing the dependence on user interaction. This feature results in a more consistent response on hydropower production to climate change compared with earlier analyses.

**Power system input data**
The system is modeled as the current system modified with expected changes for 2020. The model contains a description of 110 thermal power plants in the Nordic countries, described by capacity and marginal cost. Marginal costs are calculated on basis of predictions for fuel- and $CO_2$-quota prices, combined with efficiency and fuel input parameters for each individual power plant. Expected capacity development towards 2020 is based on Eurelectric's statistics report (Eurelectric 2009). The model includes 1108 hydro-power modules with a detailed description of reservoirs, discharge and relevant constraints. Electricity prices in continental Europe are given exogenously.

**Results**
The predicted average annual inflow represents an increase of 10-12 % compared to reference conditions. A significant part of this increase stems from more inflow during the winter season.

Hydropower production is expected to increase with 9-10 % for the NordPool region.

Spillage is expected to increase with 35 – 40 % for the NordPool region. We find that spillage during winter is the major component in the increase.

Reservoir handling is expected to change towards less variation in reservoir levels over the year. The main reason is that reservoirs will be less empty during late winter/early spring.

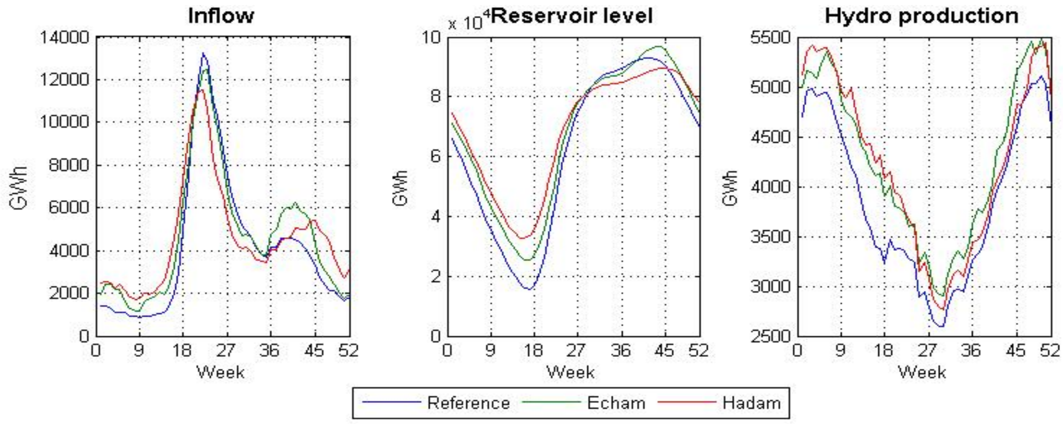


**Figure 1: Average annual properties for the NordPool region, (GWh)**

Annual average thermal production is expected to decrease with 7-8 % for the NordPool region. No particular seasonal pattern has been found.

Annual average demand decreases with 2 - 2.5 % for the NordPool region. The decrease is relatively stronger during winter than summer.

Electricity spot prices go down in all countries in the future climate scenarios. The reduction in Denmark is relatively small compared to the other countries, due to its strong connection to the European market and its lack of hydropower generation. The probability for high prices during late winter is reduced for all countries and the probability for long periods with low prices during summer increases.

All countries (excluding Finland) increase their net export to continental Europe. The hydro dominated systems (Norway and Sweden) also increase their net export to other NordPool countries. Total net export increases for the hydro dominated systems while Denmark and Finland reduce their total net export. All countries except Finland are net exporters in the climatic scenarios.

Due to the reduction in thermal power production, all countries contribute to a reduced total $CO_2$ emission in the Nordic region. The increased hydropower production stimulates more export to, and less import from continental Europe. This reduces thermal power production, and leads to reduced $CO_2$ emissions in continental Europe. This type of emission reduction can be credited to the Nordic region and represents the strongest contribution to total Nordic $CO_2$ reductions. The annual average reduction is approximately 25 Mtonne $CO_2$, or 60 %, compared to the reference.

# 1 Introduction

The objective of this study is to identify and quantify changes in generation and demand for electricity as a result of changing climatic conditions. The documented study is a part of the Nordic research project on Climate and Energy (http://en.vedur.is/ces) with funding from Nordic Energy Research.

The approach used is to simulate a given system configuration with present and predicted climate conditions. The results reflect how generation, demand, and transmission characteristics, for a fixed system configuration, respond to expected changes in inflow and temperatures.

Simulations have been carried out using SINTEF Energy Research's EMPS-model. The model is also used for hydro scheduling and investment planning (generation and transmission). The Nordic Transmission System Operators (TSOs) also use the model.

The EMPS model simulates the balance between supply and demand in a geographically distributed electricity market for a selection of historical weather years. The weather years represents hydrology, temperature and wind speed variations. The hydrology affects hydropower generation, temperature affects the load, and wind speed influence the generation from windmills. Because the production system is given exogenously, the model will not give optimal investment in new production or transmission equipment. For a more detailed description of the model, see (Wolfgang, Haugstad, Mo, Gjelsvik, Wangensteen, & Doorman, Hydro reservoir handling in Norway before and after deregulation, 2009).

Production, transmission and load for the Scandinavian system is referred to year 2020. The climatic scenarios used in the simulation are either referred to the period 1961-1990 (reference) or to the period 2021-2050 (climatic scenarios).

The input time series for hydrology and temperature has weekly time resolution. Under the assumption that there has been no climatic change during the period 1961-1990, the time series should reflect the natural variations in hydrology, temperature, and wind speed, including correlations between the different variables. The climatic scenarios are included in the energy analysis by a linear scaling approach. This means that the climatic scenario time series are created by manipulation of the historical series, based on the forecasted series for future climatic conditions. The scaling changes the average and the seasonal variation. For a more detailed specification of the scaling approach, we refer to the report "Climate change – Consequences for the electricity system" (2).

The temperature series used in the model refer to major load areas. In the applied data, we have historical and predicted time series for the period 1961-1990 and 2021-2050 for Helsinki, Stockholm, Oslo, Bergen, Trondheim and Tromsø.

In this analysis, the NordPool area, consisting of Norway, Sweden, Denmark and Finland, is modeled in detailed areas. See section 3.1 for more details on the area division. Transmission ties to other countries (The Netherlands, Germany, Poland, the Baltics and Russia) are also modeled.

Some results are presented on a temporal basis. In these presentations, the term summer refers the period from week 16 to week 43, and winter refers to the period from week 44 to week 15.

# 2 Climate scenarios

This section gives a short description of the climatic data received from other workgroups. For further description of the data, we refer to the reports written by the respective workgroups.

All groups have submitted climate data for the period 1961-1990 (Reference period) and 2021-2050 (climatic scenario) from the models "met.no-HIRHAM-HadCM3-A1B" and "DMI-HIRHAM-Echam5-A1B". The climatic scenarios are denoted Echam and Hadam. As reference, observations from the period 1961-1990 are used.

## 2.1 Inflow

Inflow series were prepared by scaling the observed inflow in the reference period with the relative change between the hydrological models' reference period and climatic scenario period. A detailed description of the method is available in Mo, Doorman and Grinden (2006). Figure 2.1 shows as an example the average weekly inflow for three specific inflow series, one in each country.

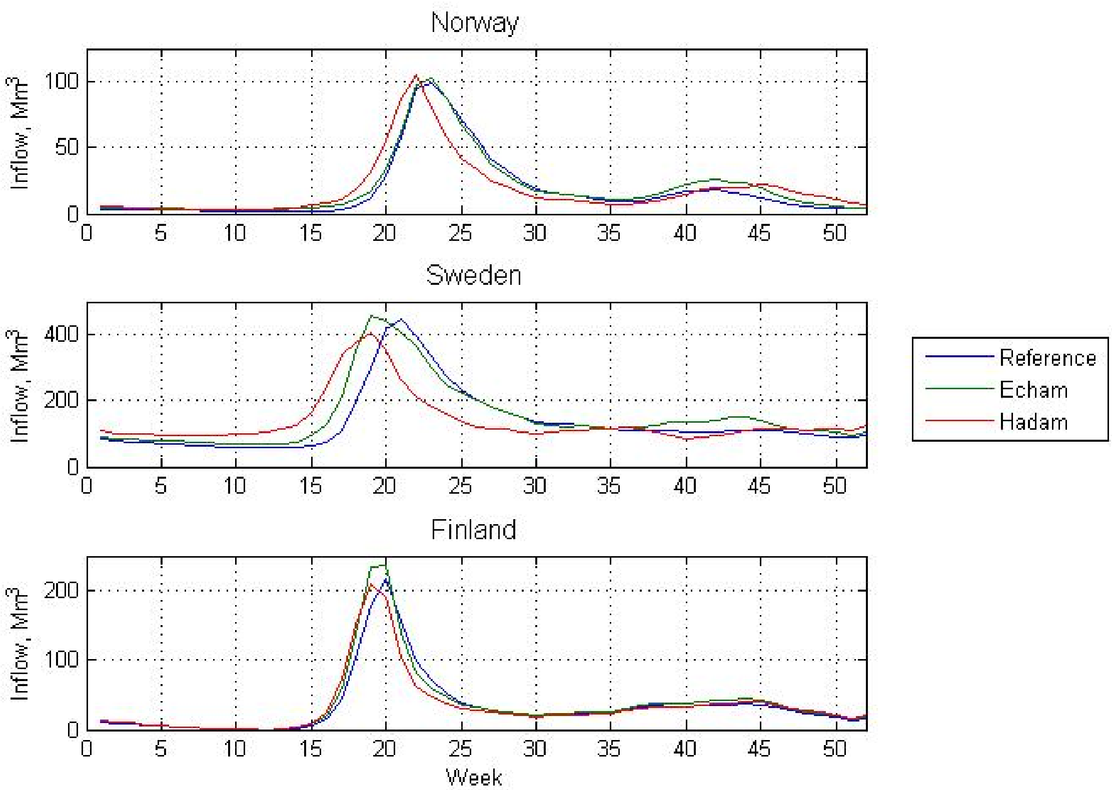


**Figure 2.1: Example inflow series, average weekly inflow in Norway, Sweden and Finland, Mm$^3$**

## 2.2 Temperatures

Average weekly temperatures for six different Nordic cities, for the reference case and the climatic scenarios, are given in Figure 2.2. By comparing the reference scenario to the predicted climatic scenarios, we find a general increase in temperatures over the year for both Echam and Hadam, and that temperatures increase more during winter than summer. Tromsø (northern Norway) seems to have a particularly large increase in temperature for Hadam.

Table 2.1 shows average daily temperatures for all 30 years in the data period. The table is intended to provide a brief quantitative comparison between climatic scenarios and the reference. We see that temperatures in general increase with 1-2 degrees Celsius for the climatic scenarios. The difference between Echam and Hadam is relatively small. As already mentioned, Tromsø deviates from the other cities, and Hadam predicts the increase in average daily temperature to 5.1 degrees Celsius.

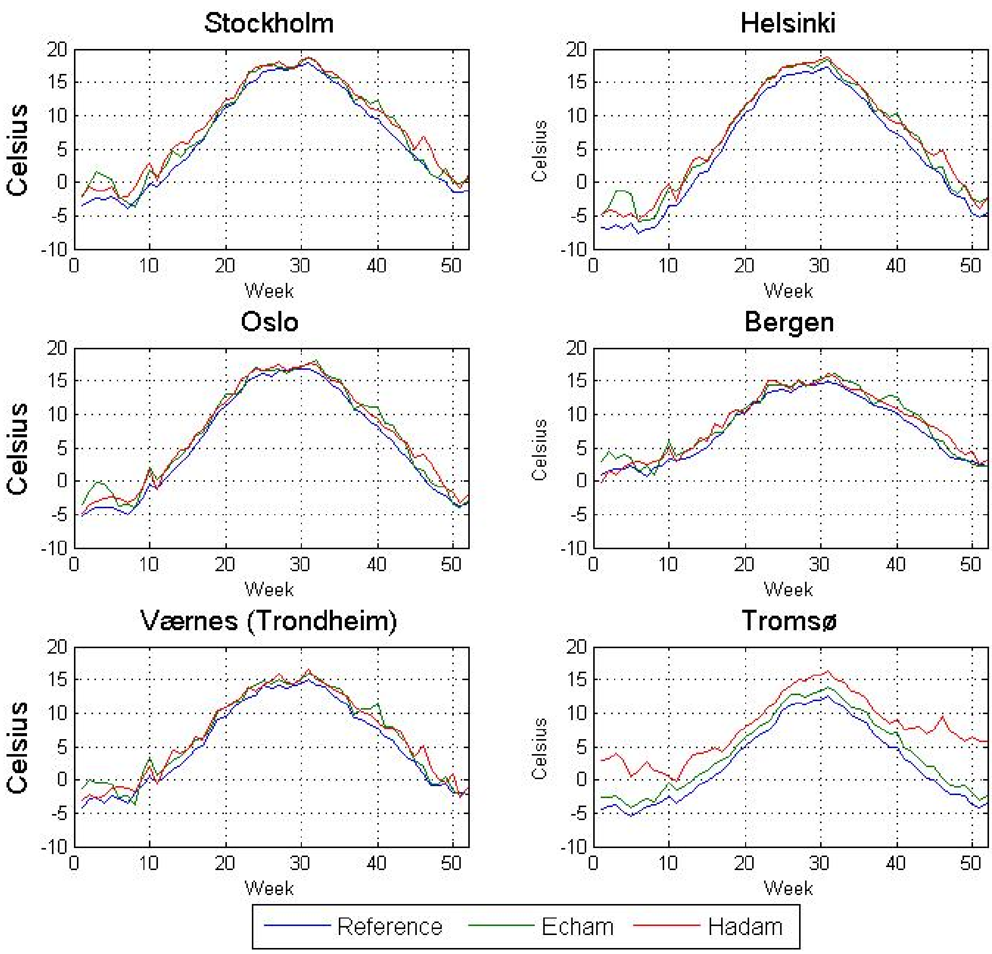


**Figure 2.2: Average weekly temperatures (Celsius)**

**Table 2.1: Average daily temperature (Celsius)**

| Celsius | Reference | Echam | Hadam |
|---|---|---|---|
| Stockholm | 6.7 | 7.8 | 8.3 |
| Helsinki | 4.6 | 6.4 | 6.5 |
| Oslo | 5.8 | 6.9 | 7.0 |
| Bergen | 7.7 | 8.6 | 8.6 |
| Værnes | 5.4 | 6.6 | 6.6 |
| Tromsø | 2.6 | 4.0 | 7.7 |

# 3 Power market assumptions

This section outlines how the 2020 power system has been modeled.

The power system configuration is modeled as today's system modified with expected changes for 2020. The model of today's system contains a detailed description of all relevant thermal power plants in the NordPool countries, and includes capacities (profiles over the year where applicable) and marginal cost. Marginal costs are calculated based on given predictions for 2020 fuel and $CO_2$-quota prices, combined with efficiency and fuel input parameters for each individual power plant.

## 3.1 Area model

In our EMPS model, the countries that constitute the NordPool electricity market are divided in 23 areas as shown in Table 3.1.

**Table 3.1: Area numbering**

| | |
|---|---|
| Norway | [1] – Glomma<br>[2] – Østlandet<br>[3] – Southeast<br>[4] – Hallingdal<br>[5] – Telemark<br>[6] – South<br>[7] – SouthWest<br>[8] – West<br>[9] – Central<br>[10] – Helgeland<br>[11] – Troms<br>[12] – Finnmark |
| Sweden | [13] – Ovre Norrland 1 (Luleåelven)<br>[14] – Ovre Norrland2 (Umeå and Skjelefteåelven)<br>[15] – Nedre Norrland 2 (Ångermannselven)<br>[16] – Nedre Norrland 2 (Inndalselven)<br>[17] – Central (Ljungan, Ljusnan, Dalaelven)<br>[18] – South |
| Denmark | [19] – West<br>[20] – East |
| Finland | [21] – Central<br>[22] – North<br>[23] – South<br>(North and South represent Finnish hydro and wind production only, while Central includes all Finnish load and thermal production) |

The number within the brackets [] shows the area number used in Figure 3.1.

Between these areas there are limited exchange capacities. Interconnections to the Netherlands, Germany, the Baltics and Poland are also modelled. This is described in sections 3.4 and 3.5.

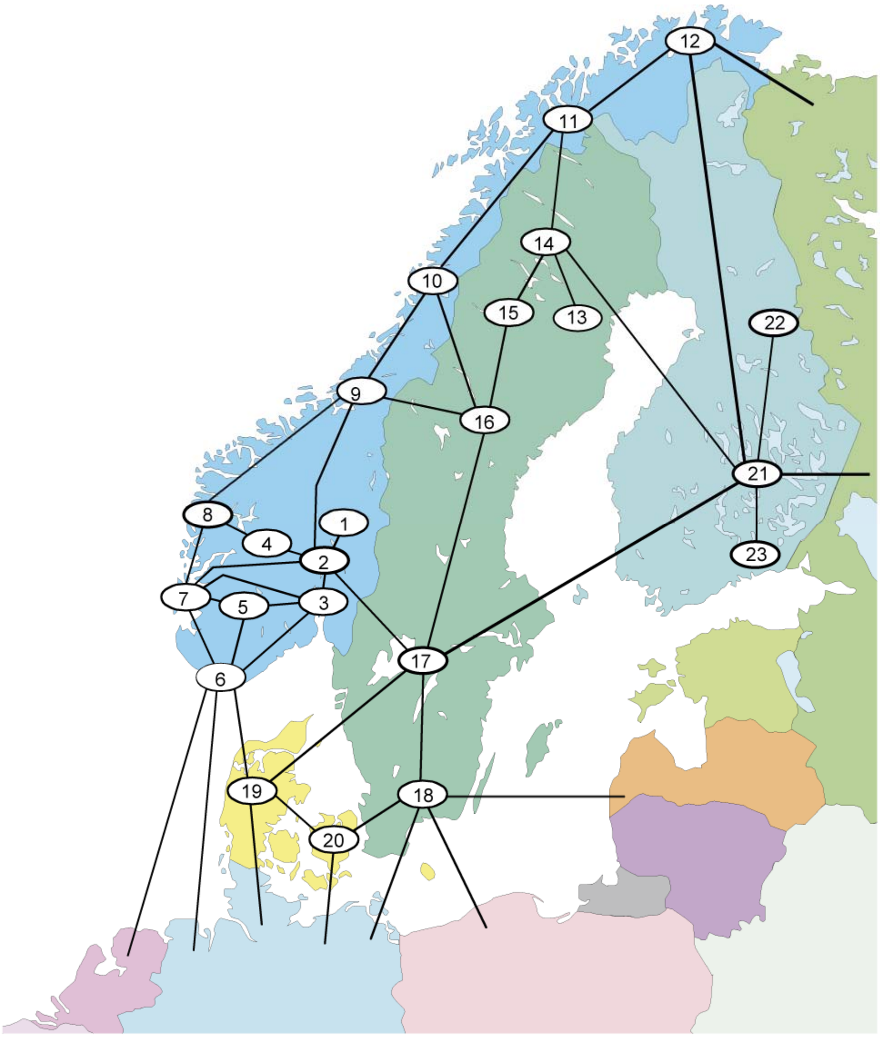


**Figure 3.1: Areas and interconnections used in simulations**

## 3.2 Generation capacity

Table 3.2 shows the 2020 system generation capacity used in the analysis, given for each country and type of production. The generation capacities are based on predictions from the Eurelectric report for 2020 (Eurelectric, 2009).

**Table 3.2: Generation capacity, 2020 (GW)**

| Country | Nuclear | Thermal | Hydro | Wind | Sum |
|---|---|---|---|---|---|
| **Denmark** | 0.0 | 8.9 | 0.0 | 5.6 | **14.5** |
| **Sweden** | 10.0 | 6.2 | 16.4 | 6.0 | **38.7** |
| **Finland** | 5.9 | 10.8 | 3.4 | 1.5 | **21.5** |
| **Norway** | 0.0 | 1.5 | 29.5 | 1.7 | **32.6** |
| **Sum** | **15.9** | **27.3** | **49.3** | **14.8** | **107.3** |

For comparison, the changes, in absolute and relative terms, from the 2010 system are shown in Table 3.3. Major changes include a large increase in nuclear capacity in Finland, and a significant increase in wind power production for all countries.

**Table 3.3: Absolute and relative change in generation capacity**

| | Nuclear | | Thermal | | Hydro | | Wind | | Sum | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Unit** | **GW** | **%** | **GW** | **%** | **GW** | **%** | **GW** | **%** | **GW** | **%** |
| **Denmark** | 0.0 | 0 | -0.3 | -3 | 0.0 | 0 | 1.9 | 51 | **1.6** | **12** |
| **Sweden** | 0.5 | 5 | -1.5 | -19 | 0.2 | 1 | 4.4 | 275 | **3.6** | **10** |
| **Finland** | 3.2 | 119 | -0.5 | -4 | 0.3 | 8 | 1.3 | 525 | **4.2** | **25** |
| **Norway** | 0.0 | 0 | 0.8 | 108 | 0.4 | 1 | 0.7 | 67 | **1.8** | **6** |
| **Sum** | **3.7** | **30** | **-1.5** | **-5** | **0.9** | **2** | **8.2** | **126** | **11.3** | **12** |

**Hydro**
The hydro system model encompasses 1108 modules (i.e. rivers and reservoirs), divided into subsystems according to their geographical location. Each module can be described by the following properties:

- A reservoir, defined by its volume and relationship between water volume and elevation.
- A plant, defined by its discharge capacity and a piecewise linear relationship between discharge and generation (generation is also corrected for variations in water head, but head is not included in the optimization problem).
- Different destinations for plant discharge, bypass discharge and reservoir overflow (spillage).
- Variable constraints on reservoir contents and water flow (plant and bypass discharge).
- Pumping capability, either reversible turbines or dedicated pumping turbines.

A subsystem example and an illustration of the module properties is shown in the appendix.

**Nuclear and other thermal**
The model includes approximately 110 thermal power production units. Each unit is described by production capacity and marginal production cost.

**Wind**
Wind power production units are modeled as hydropower modules with no reservoir capacity, and aggregated into a single module for each wind power area. Our model comprises 16 wind areas.

## 3.3 Marginal costs for thermal power production

Marginal costs are calculated on the basis of efficiencies and 2020-predictions for fuel- and $CO_2$-quota prices provided by the project partner Energianalyse[1], cf. Table 3.4. Energianalyse also provided predicted $CO_2$-quota price for 2020. The predicted price was 30.24 EUR per tonne emitted $CO_2$.

**Table 3.4: Theoretical cost of generation by fuel type**

| Fuel type | Theoretical[2] cost (EUR/MWh) |
|---|---|
| Hard coal | 13.2 |
| Lignite | 10.6 |
| Bio | 31.7 |
| Gas oil | 69.7 |
| Heavy fuel oil | 39.4 |
| Gas | 35.3 |

**Table 3.5: Theoretical emission of CO2 and emission price by fuel type**

| Fuel type | Theoretical emission (g/kWh) | Theoretical cost (EUR/MWh) |
|---|---|---|
| Hard coal | 370 | 11.2 |
| Lignite | 500 | 15.1 |
| Bio | 0 | 0.0 |
| Gas oil | 300 | 9.1 |
| Heavy fuel oil | 350 | 10.6 |
| Gas | 200 | 6.0 |

## 3.4 Interconnections

The interconnection setup for 2020 is based on various reports predictions, (Statnett, 2009), (Baltso, 2009) and (Nordel, 2008), combined with a subjective assessment of what might be a likely outcome. The modeled transmission grid between areas in the NordPool system is shown in Table 3.6. Interconnections to and from non-NordPool countries and the adjacent capacities are shown in Table 3.7.

[1] www.energianalyse.dk, 01.02.2010
[2] The term "theoretical" refers to the theoretical energy (heat) the fuel contains, and should not be confused with the price of producing a unit of electrical energy, which depends on how efficient a power plant can utilize the theoretical energy in the fuel.

**Table 3.6: Internal NordPool interconnections and capacities (MW)**

| From [Area] | To [Area] | Capacity out (MW) | Capacity in (MW) | From [Area] | To [Area] | Capacity out (MW) | Capacity in (MW) |
|---|---|---|---|---|---|---|---|
| [1] | [2] | 5000 | 5000 | [10] | [9] | 900 | 900 |
| [2] | [17] | 2200 | 2200 | [10] | [16] | 150 | 250 |
| [3] | [2] | 2000 | 2000 | [11] | [10] | 600 | 600 |
| [4] | [2] | 3300 | 3300 | [11] | [14] | 700 | 700 |
| [5] | [3] | 1800 | 1800 | [12] | [11] | 150 | 150 |
| [6] | [3] | 800 | 600 | [12] | [21] | 120 | 100 |
| [6] | [5] | 800 | 800 | [13] | [14] | 2700 | 2700 |
| [6] | [19] | 1500 | 1500 | [14] | [21] | 1650 | 1050 |
| [7] | [6] | 1200 | 1200 | [14] | [15] | 4000 | 4000 |
| [7] | [5] | 900 | 900 | [15] | [16] | 6000 | 6000 |
| [7] | [8] | 500 | 500 | [16] | [17] | 7000 | 7000 |
| [7] | [2] | 900 | 900 | [17] | [21] | 550 | 550 |
| [7] | [3] | 1000 | 1000 | [17] | [19] | 720 | 720 |
| [8] | [4] | 2600 | 2600 | [17] | [18] | 4500 | 4500 |
| [8] | [9] | 2000 | 2000 | [18] | [20] | 3775 | 3700 |
| [9] | [2] | 600 | 600 | [20] | [19] | 600 | 600 |
| [9] | [16] | 1950 | 1950 | [20] | [19] | 600 | 600 |

**Table 3.7: Interconnections and capacities to non-NordPool countries (MW)**

| | Denmark, east [20] | Denmark, west [19] | Sweden, south [18] | Norway, south [6] |
|---|---|---|---|---|
| The Netherlands | - | - | - | 700 |
| Germany | 600 | 2500 | 600 | 1400 |
| Poland | - | - | 600 | - |
| Baltic | - | - | 600 | - |

## 3.5 Exchange prices to continental Europe

Prices for exchange with non-NordPool countries have been given exogenously in the model for day, night and weekend. The estimated prices are based on the exchange between Denmark and Germany, and as a simplification applied on all exchanges to continental Europe.

A report in World Power 2008, (7), states that marginal production during peak hours (i.e. Daytime) in Germany is mainly provided by gas based units, while in off-peak hours (i.e. nighttime) by coal based units. Prices were estimated using marginal costs for German thermal production units. Marginal costs were updated for 2020 predicted fuel and $CO_2$-quota prices. The daytime-price in Germany was set to the average marginal cost for a selection of production units using gas as primary fuel (6.80 EURc/kWh). Night and weekend prices were estimated using historical data for hourly prices on the Kontek transmission[3] (between Germany and Denmark) for 2009 to find the relative relationship between day, night, and weekend, as shown in Table 3.8.

**Table 3.8: Average prices, Kontek-transmission, 2009 (EUR/MWh)**

| | Day | Night | Weekend |
|---|---|---|---|
| Observed Average price 2009 | 45.52 | 25.04 | 37.81 |
| Relative to day price (%) | 100 | 55 | 83 |

By applying the same relative relationship between prices as in Table 3.10 to 2020, the export/import-prices were calculated as shown in Table 3.9.

**Table 3.9: Estimated export/import prices in non-NordPool countries (EURc/kWh)**

| | Day | Night | Weekend |
|---|---|---|---|
| Estimated price for 2020 | 6.80 | 3.73 | 5.64 |

The prices were further adjusted to account for an assumed transmission loss of 2 % to/from Germany, Poland and the Baltics, and 4 % to/from the Netherlands. The adjusted prices are shown in Table 3.10.

**Table 3.10: Estimated export/import prices adjusted for transmission loss (EURc/kWh)**

| | The Netherlands | | Germany/Poland/Baltics | |
|---|---|---|---|---|
| | Import | Export | Import | Export |
| Day | 7.07 | 6.52 | 6.93 | 6.66 |
| Night | 3.89 | 3.59 | 3.81 | 3.66 |
| Weekend | 5.87 | 5.42 | 5.76 | 5.53 |

## 3.6 Demand

Predicted power consumption is based on forecasts from the Eurelectric report (3). The forecasts are shown in table Table 3.11. The power consumption is distributed to areas for all countries. It should be noted that simulated consumption might differ somewhat from the stated consumption, as demand is adjusted in the model according to changes in temperature.

**Table 3.11: Power consumption in 2020, (TWh/year)**

| Country | Power consumption (TWh/year) |
|---|---|
| Norway | 142.7 |
| Sweden | 144.0 |
| Finland | 101.3 |
| Denmark | 38.2 |
| Sum | 426.2 |

[3] ftp://194.19.110.71/Elspot/Elspot_prices/Kontek/2008/, 01.02.2010

# 4 Results

This section presents the simulation results. We focus on comparing the reference case and the climatic scenarios. Results are presented for different regions and time of year.[4] The following results are included:

1. Hydro power generation
2. Spillage
3. Reservoir handling
4. Wind power generation
5. Thermal power generation
6. Demand
7. Prices
8. Export and import
9. Energy balances
10. $CO_2$-emissions

## 4.1 Inflow

Average annual inflow in TWh per year, for country, region and season are shown in Table 4.1. The absolute and relative changes in the climatic scenarios compared to the reference case are shown in Table 4.2 and Table 4.3. A graphical presentation is given in Figure 4.1. For the NordPool system in total, the reference simulation has a total average annual inflow of 214.9 TWh. For Echam and Hadam, inflow increase to respectively 240.7 and 238.3 TWh. In relative terms, the increase amounts to 12 % and 10.9 %, respectively. A significant part of the increase stems from more inflow during winter, which amounts to 45 % for Echam and 87 % for Hadam. For the Norwegian inflow, we find that while summer inflow seems to be relatively similar over all scenarios, the winter inflow increases with 60 % for Echam and 115 % for Hadam. No Norwegian region seems to contribute more to this than other regions, in relative terms. For Sweden, the corresponding winter inflow increase is smaller, 30 % increase for Echam and 68 % for Hadam. Also here we see that the different regions contribute relatively similarly to the total increase. For Finland, the corresponding winter inflow increase is smaller, 18 % increase for Echam and 22 % for Hadam.

[4] Summer refer to week 16 to week 43, winter refer to week 44 to week 17.

**Table 4.1: Average annual inflow, (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 46.1 | 9.4 | 55.6 | 48.1 | 15.4 | 63.5 | 43.4 | 20.5 | 63.9 |
| West Norway | 33.2 | 6.2 | 39.3 | 36.0 | 9.7 | 45.7 | 30.2 | 12.9 | 43.1 |
| Central Norway | 11.7 | 2.8 | 14.5 | 11.3 | 4.1 | 15.4 | 10.3 | 5.5 | 15.8 |
| North Norway | 16.5 | 3.2 | 19.7 | 15.4 | 5.2 | 20.6 | 14.8 | 7.6 | 22.4 |
| **Sum Norway** | **107.6** | **21.6** | **129.1** | **110.8** | **34.4** | **145.2** | **98.7** | **46.5** | **145.2** |
| | | | | | | | | | |
| North Sweden | 44.1 | 7.8 | 51.9 | 46.4 | 10.3 | 56.7 | 42.0 | 14.4 | 56.4 |
| Central Sweden | 9.3 | 2.9 | 12.2 | 10.5 | 3.7 | 14.2 | 9.0 | 5.0 | 14.1 |
| South Sweden | 3.4 | 3.4 | 6.9 | 3.8 | 4.5 | 8.3 | 3.2 | 4.4 | 7.5 |
| **Sum Sweden** | **56.8** | **14.2** | **70.9** | **60.7** | **18.5** | **79.2** | **54.2** | **23.8** | **78.0** |
| | | | | | | | | | |
| **Finland** | **10.3** | **4.5** | **14.9** | **11.0** | **5.3** | **16.3** | **9.7** | **5.5** | **15.1** |
| | | | | | | | | | |
| **Nord Pool area** | **174.7** | **40.2** | **214.9** | **182.5** | **58.2** | **240.7** | **162.5** | **75.8** | **238.3** |

**Table 4.2: Absolute change in inflow compared to reference case (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 2.0 | 6.0 | 7.9 | -2.7 | 11.1 | 8.3 |
| West Norway | 2.8 | 3.5 | 6.4 | -3.0 | 6.7 | 3.8 |
| Central Norway | -0.4 | 1.3 | 0.9 | -1.4 | 2.7 | 1.3 |
| North Norway | -1.1 | 2.0 | 0.9 | -1.7 | 4.4 | 2.7 |
| **Sum Norway** | **3.2** | **12.8** | **16.1** | **-8.9** | **24.9** | **16.1** |
| | | | | | | |
| North Sweden | 2.3 | 2.5 | 4.8 | -2.1 | 6.6 | 4.5 |
| Central Sweden | 1.2 | 0.8 | 2.0 | -0.3 | 2.1 | 1.9 |
| South Sweden | 0.4 | 1.1 | 1.4 | -0.2 | 1.0 | 0.6 |
| **Sum Sweden** | **3.9** | **4.3** | **8.3** | **-2.6** | **9.6** | **7.1** |
| | | | | | | |
| **Finland** | **0.7** | **0.8** | **1.4** | **-0.6** | **1.0** | **0.2** |
| | | | | | | |
| **Nord Pool area** | **7.8** | **18.0** | **25.8** | **-12.2** | **35.6** | **23.4** |

**Table 4.3: Relative change in inflow compared to reference case (%)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 4.3 | 63.8 | 14.2 | -5.9 | 118.1 | 14.9 |
| West Norway | 8.4 | 56.5 | 16.3 | -9.0 | 108.1 | 9.7 |
| Central Norway | -3.4 | 46.4 | 6.2 | -12.0 | 96.4 | 9.0 |
| North Norway | -6.7 | 62.5 | 4.6 | -10.3 | 137.5 | 13.7 |
| **Sum Norway** | **3.0** | **59.3** | **12.5** | **-8.3** | **115.3** | **12.5** |
| | | | | | | |
| North Sweden | 5.2 | 32.1 | 9.2 | -4.8 | 84.6 | 8.7 |
| Central Sweden | 12.9 | 27.6 | 16.4 | -3.2 | 72.4 | 15.6 |
| South Sweden | 11.8 | 32.4 | 20.3 | -5.9 | 29.4 | 8.7 |
| **Sum Sweden** | **6.9** | **30.3** | **11.7** | **-4.6** | **67.6** | **10.0** |
| | | | | | | |
| **Finland** | **6.8** | **17.8** | **9.4** | **-5.8** | **22.2** | **1.3** |
| | | | | | | |
| **Nord Pool area** | **4.5** | **44.8** | **12.0** | **-7.0** | **88.6** | **10.9** |

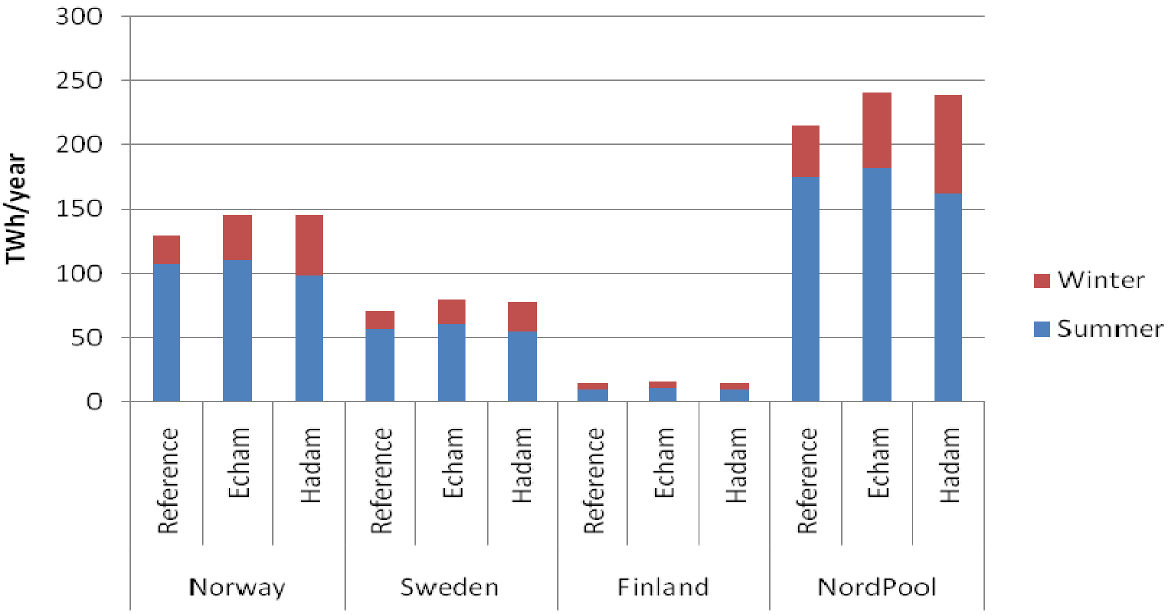


**Figure 4.1: Average annual inflow, (TWh per year)**

For further examination of inflow, a visual presentation with higher time resolution is given in Figure 4.2 and Figure 4.3. The figures shows the characteristics already pointed out, i.e. more inflow in the winter, and less or equal during summer. For an equivalent presentation for regions, see Appendix Figure 6.3 and Figure 6.4.

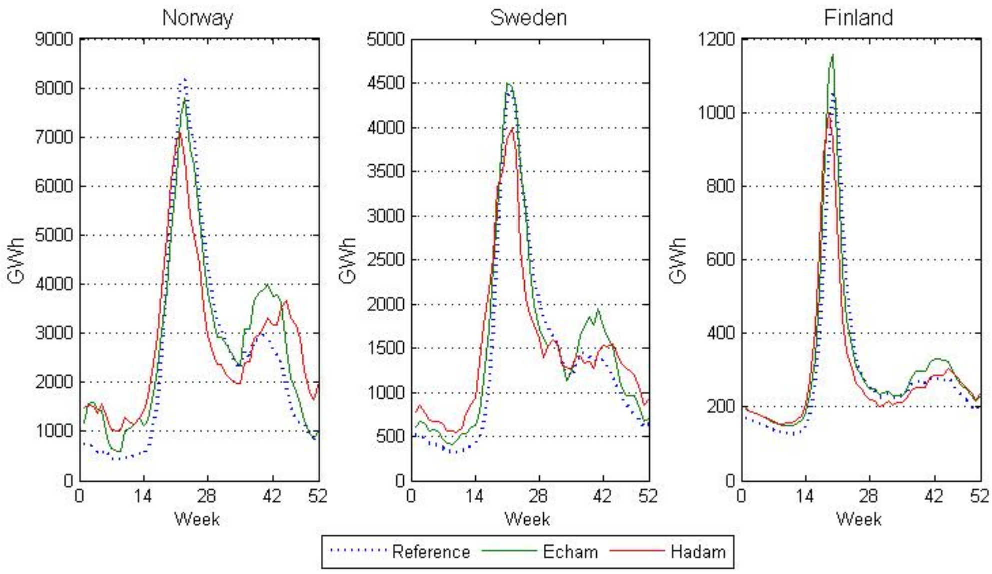


**Figure 4.2: Average weekly inflow over the year, (GWh/week)**

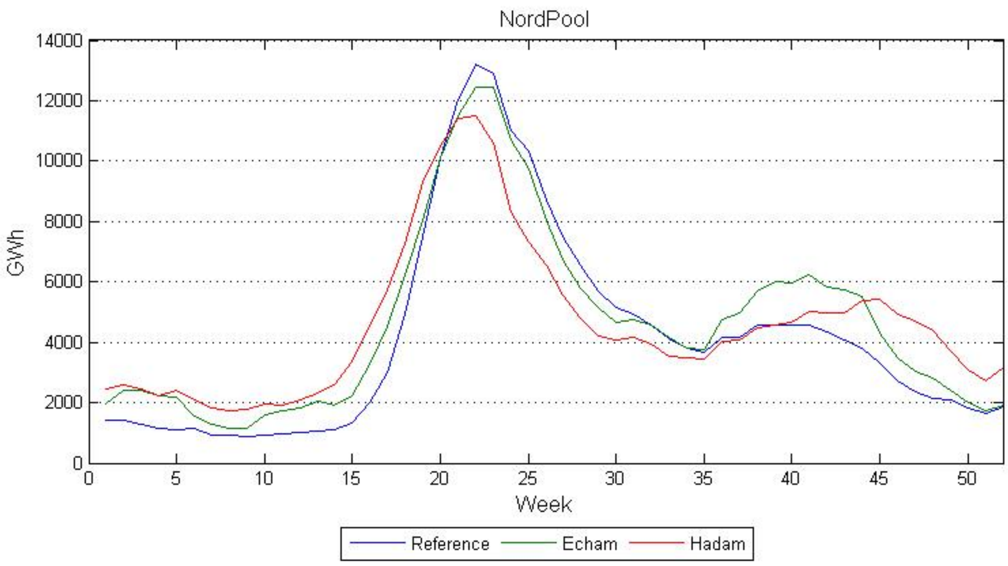


**Figure 4.3: Average weekly inflow in NordPool area over the year (GWh/week)**

Figure 4.4 shows the distribution of inflow levels over the year, represented by percentiles, for the entire NordPool area. If we compare Echam and Hadam to the reference, we see that level and variance is relatively similar during summer, while during winter, both level and variance seems to increase.

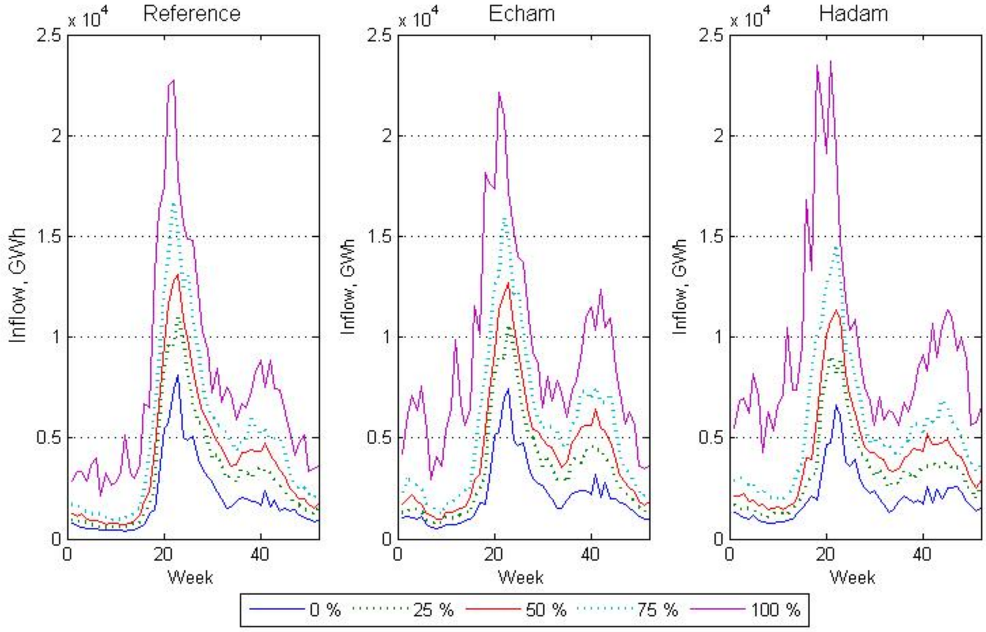


**Figure 4.4: Inflow distribution in NordPool area over the year, (GWh/week)**

## 4.2 Hydropower generation

Hydropower generation correlates with inflow on an annual basis. Increased inflow is also expected to cause increased spillage/overflow. Table 4.4 shows average annual hydropower production for all countries, regions and scenarios, in TWh per year. An overview of annual hydropower production is given in Figure 4.5.

Table 4.5 shows changes in respectively absolute and relative terms, comparing the climatic scenarios to the reference case. A brief examination reveals that the annual hydropower production increases with about 10 % for all countries with both Echam and Hadam, and that difference between the two scenarios are relatively small. The increase in generation is approximately the same for winter and summer.

The seasonal pattern for production is not necessarily the same as for inflow. Figure 4.6 shows the average weekly hydropower production over the year, together with inflow. Comparing climatic scenarios to the reference, we see that the increase in production is distributed evenly throughout the year.

**Table 4.4: Average annual hydropower production, (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 23.6 | 28.0 | 51.6 | 27.0 | 31.5 | 58.5 | 26.8 | 31.8 | 58.6 |
| West Norway | 14.8 | 22.4 | 37.3 | 17.0 | 25.4 | 42.4 | 15.5 | 24.8 | 40.3 |
| Central Norway | 6.1 | 7.6 | 13.7 | 6.0 | 8.4 | 14.4 | 5.5 | 9.1 | 14.5 |
| North Norway | 7.0 | 11.7 | 18.7 | 7.6 | 11.9 | 19.5 | 8.3 | 12.4 | 20.7 |
| **Sum Norway** | **51.5** | **69.7** | **121.1** | **57.6** | **77.1** | **134.7** | **56.1** | **78.1** | **134.2** |
| | | | | | | | | | |
| North Sweden | 20.5 | 29.3 | 49.8 | 23.3 | 30.6 | 53.9 | 23.9 | 29.9 | 53.8 |
| Central Sweden | 5.8 | 5.2 | 11.0 | 6.4 | 5.9 | 12.3 | 6.0 | 6.3 | 12.3 |
| South Sweden | 2.9 | 3.1 | 6.0 | 3.2 | 3.7 | 6.9 | 2.9 | 3.5 | 6.5 |
| **Sum Sweden** | **29.2** | **37.6** | **66.9** | **32.9** | **40.1** | **73.1** | **32.9** | **39.8** | **72.7** |
| | | | | | | | | | |
| **Finland** | **6.9** | **6.9** | **13.8** | **7.5** | **7.3** | **14.7** | **6.6** | **7.2** | **13.8** |
| | | | | | | | | | |
| **Nord Pool area** | **87.6** | **114.2** | **201.8** | **98.0** | **124.5** | **222.5** | **95.6** | **125.1** | **220.7** |

**Table 4.5: Absolute change in hydropower production compared to reference case (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 3.4 | 3.5 | 6.9 | 3.2 | 3.8 | 7.0 |
| West Norway | 2.2 | 3.0 | 5.1 | 0.7 | 2.4 | 3.0 |
| Central Norway | -0.1 | 0.8 | 0.7 | -0.6 | 1.5 | 0.8 |
| North Norway | 0.6 | 0.2 | 0.8 | 1.3 | 0.7 | 2.0 |
| **Sum Norway** | **6.1** | **7.4** | **13.6** | **4.6** | **8.4** | **13.1** |
| | | | | | | |
| North Sweden | 2.8 | 1.3 | 4.1 | 3.4 | 0.6 | 4.0 |
| Central Sweden | 0.6 | 0.7 | 1.3 | 0.2 | 1.1 | 1.3 |
| South Sweden | 0.3 | 0.6 | 0.9 | 0.0 | 0.4 | 0.5 |
| **Sum Sweden** | **3.7** | **2.5** | **6.2** | **3.7** | **2.2** | **5.8** |
| | | | | | | |
| **Finland** | **0.6** | **0.4** | **0.9** | **-0.3** | **0.3** | **0.0** |
| | | | | | | |
| **Nord Pool area** | **10.4** | **10.3** | **20.7** | **8.0** | **10.9** | **18.9** |

**Table 4.6: Relative change in hydropower production compared to reference case (%)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 14.4 | 12.5 | 13.4 | 13.6 | 13.6 | 13.6 |
| West Norway | 14.9 | 13.4 | 13.7 | 4.7 | 10.7 | 8.0 |
| Central Norway | -1.6 | 10.5 | 5.1 | -9.8 | 19.7 | 5.8 |
| North Norway | 8.6 | 1.7 | 4.3 | 18.6 | 6.0 | 10.7 |
| **Sum Norway** | **11.8** | **10.6** | **11.2** | **8.9** | **12.1** | **10.8** |
| | | | | | | |
| North Sweden | 13.7 | 4.4 | 8.2 | 16.6 | 2.0 | 8.0 |
| Central Sweden | 10.3 | 13.5 | 11.8 | 3.4 | 21.2 | 11.8 |
| South Sweden | 10.3 | 19.4 | 15.0 | 0.0 | 12.9 | 8.3 |
| **Sum Sweden** | **12.7** | **6.6** | **9.3** | **12.7** | **5.9** | **8.7** |
| | | | | | | |
| **Finland** | **8.7** | **5.8** | **6.5** | **-4.3** | **4.3** | **0.0** |
| | | | | | | |
| **Nord Pool area** | **11.9** | **9.0** | **10.3** | **9.1** | **9.5** | **9.4** |

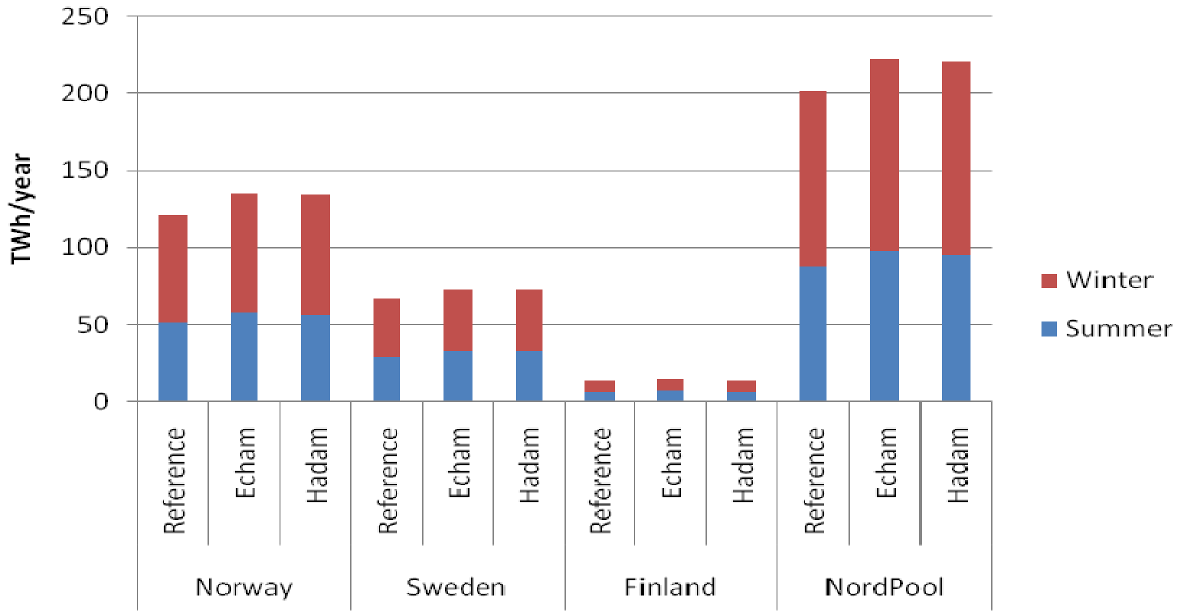


**Figure 4.5: Average annual hydropower production**

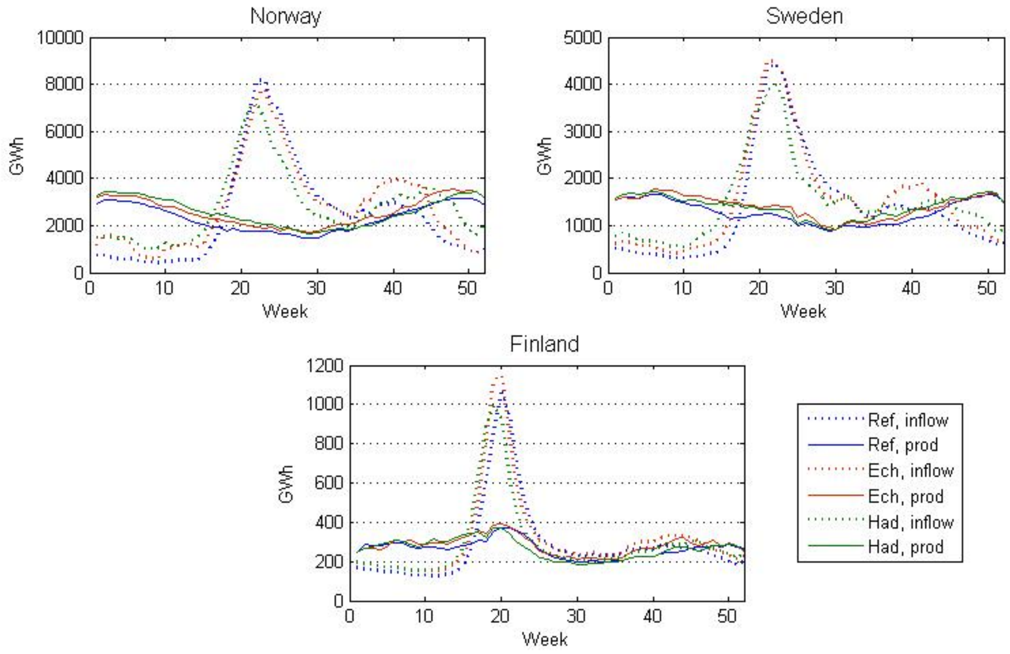


**Figure 4.6: Average annual inflow and hydropower production (GWh)**

## 4.3 Spillage

As mentioned, we expect the increase in inflow to cause more spillage/overflow from reservoirs. Table 4.7 shows the average annual spillage given in TWh per year. An overview of annual spillage is given in Figure 4.7.

Table 4.8 shows the change in spillage between the reference case and the climatic scenarios in TWh, while Table 4.9 show the equivalent relative change in percent. For the NordPool area, we find that the average annual increase in spillage is 4.8 TWh (+ 38 %) and 4.1 TWh (+ 32 %) for Echam and Hadam respectively. We also find that spillage in the winter season increases relatively more than summer spillage. Spillage during summer remains the biggest component in total average annual spillage.

**Table 4.7: Average annual spillage, (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 3.3 | 0.6 | 3.9 | 3.7 | 1.2 | 4.9 | 3.3 | 1.7 | 5.0 |
| West Norway | 1.7 | 0.3 | 2.0 | 2.5 | 0.7 | 3.2 | 1.5 | 1.1 | 2.6 |
| Central Norway | 0.7 | 0.2 | 0.9 | 0.7 | 0.2 | 0.9 | 0.7 | 0.5 | 1.2 |
| North Norway | 0.9 | 0.0 | 1.0 | 0.9 | 0.1 | 1.1 | 1.1 | 0.4 | 1.6 |
| **Sum Norway** | **6.6** | **1.1** | **7.8** | **7.8** | **2.3** | **10.1** | **6.6** | **3.8** | **10.4** |
| | | | | | | | | | |
| North Sweden | 1.5 | 0.3 | 1.9 | 2.1 | 0.5 | 2.6 | 1.5 | 0.8 | 2.3 |
| Central Sweden | 1.0 | 0.2 | 1.1 | 1.5 | 0.3 | 1.8 | 1.2 | 0.5 | 1.7 |
| South Sweden | 0.5 | 0.4 | 0.8 | 0.7 | 0.7 | 1.4 | 0.5 | 0.6 | 1.1 |
| **Sum Sweden** | **3.0** | **0.9** | **3.8** | **4.3** | **1.5** | **5.8** | **3.2** | **1.9** | **5.1** |
| | | | | | | | | | |
| **Finland** | 0.9 | 0.1 | 1.1 | 1.3 | 0.3 | 1.5 | 1.0 | 0.3 | 1.3 |
| | | | | | | | | | |
| **Nord Pool area** | **10.6** | **2.2** | **12.7** | **13.4** | **4.1** | **17.5** | **10.8** | **6.0** | **16.8** |

**Table 4.8: Absolute change in spillage compared to reference case (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 0.4 | 0.6 | 1.0 | 0.0 | 1.1 | 1.1 |
| West Norway | 0.8 | 0.4 | 1.2 | -0.2 | 0.8 | 0.6 |
| Central Norway | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 |
| North Norway | 0.0 | 0.1 | 0.1 | 0.2 | 0.4 | 0.6 |
| **Sum Norway** | **1.2** | **1.2** | **2.3** | **0.0** | **2.7** | **2.6** |
| | | | | | | |
| North Sweden | 0.6 | 0.2 | 0.7 | 0.0 | 0.5 | 0.4 |
| Central Sweden | 0.5 | 0.1 | 0.7 | 0.2 | 0.3 | 0.6 |
| South Sweden | 0.2 | 0.3 | 0.6 | 0.0 | 0.2 | 0.3 |
| **Sum Sweden** | **1.3** | **0.6** | **2.0** | **0.2** | **1.0** | **1.3** |
| | | | | | | |
| **Finland** | **0.4** | **0.2** | **0.4** | **0.1** | **0.2** | **0.2** |
| | | | | | | |
| **Nord Pool area** | **2.8** | **1.9** | **4.8** | **0.2** | **3.8** | **4.1** |

Table 4.9: Relative change in spillage compared to reference case (%)

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 12.1 | 100.0 | 25.6 | 0.0 | 183.3 | 28.2 |
| West Norway | 47.1 | 133.3 | 60.0 | -11.8 | 266.7 | 30.0 |
| Central Norway | 0.0 | 0.0 | 0.0 | 0.0 | 150.0 | 33.3 |
| North Norway | 0.0 | NA | 10.0 | 22.2 | NA | 60.0 |
| **Sum Norway** | **18.2** | **109.1** | **29.5** | **0.0** | **245.5** | **33.3** |
| | | | | | | |
| North Sweden | 40.0 | 66.7 | 36.8 | 0.0 | 166.7 | 21.1 |
| Central Sweden | 50.0 | 50.0 | 63.6 | 20.0 | 150.0 | 54.5 |
| South Sweden | 40.0 | 75.0 | 75.0 | 0.0 | 50.0 | 37.5 |
| **Sum Sweden** | **43.3** | **66.7** | **52.6** | **6.7** | **111.1** | **34.2** |
| | | | | | | |
| **Finland** | **44.4** | **200.0** | **36.4** | **11.1** | **200.0** | **18.2** |
| | | | | | | |
| **Nord Pool area** | **26.4** | **86.4** | **37.8** | **1.9** | **172.7** | **32.3** |

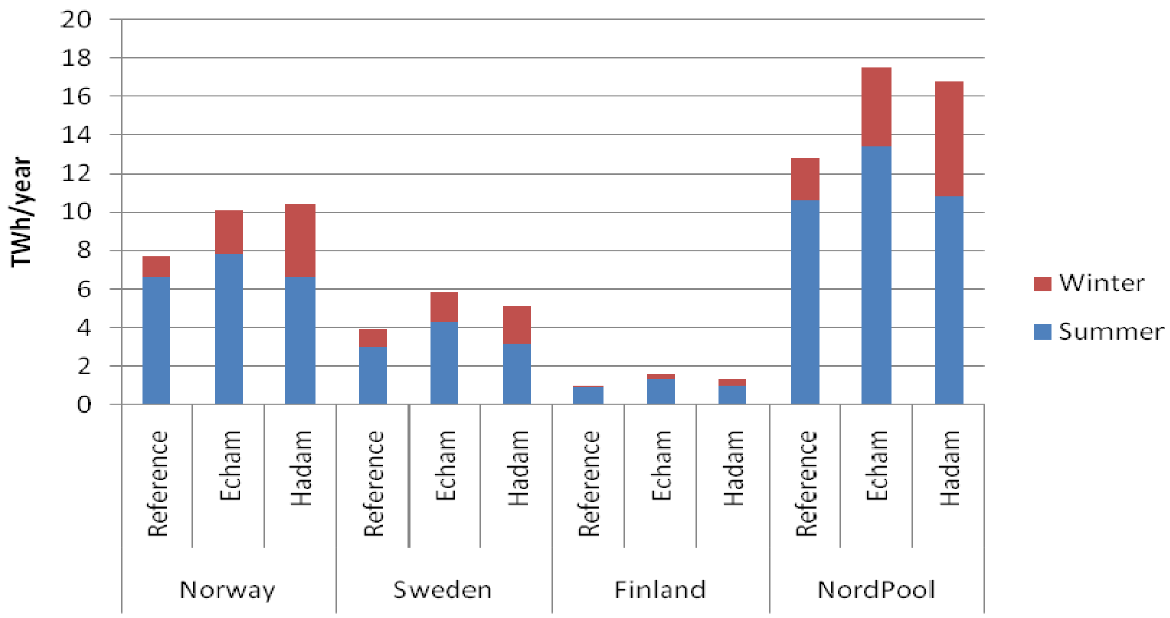


**Figure 4.7: Average annual spillage**

### 4.4 Reservoir handling

Change in inflow and demand affects the optimal drawdown strategy. Figure 4.8 shows the average weekly reservoir filling levels over the year, while Figure 4.9 shows the distribution for weekly filling levels, represented by percentiles. We find that all countries have higher average filling levels during late winter and early summer in the climatic scenarios. In the same period we also find that the variance increases. The variance and levels in late summer/early winter remains relatively similar to the reference case. For a more detailed presentation of reservoir handling, see Appendix section 6.3.

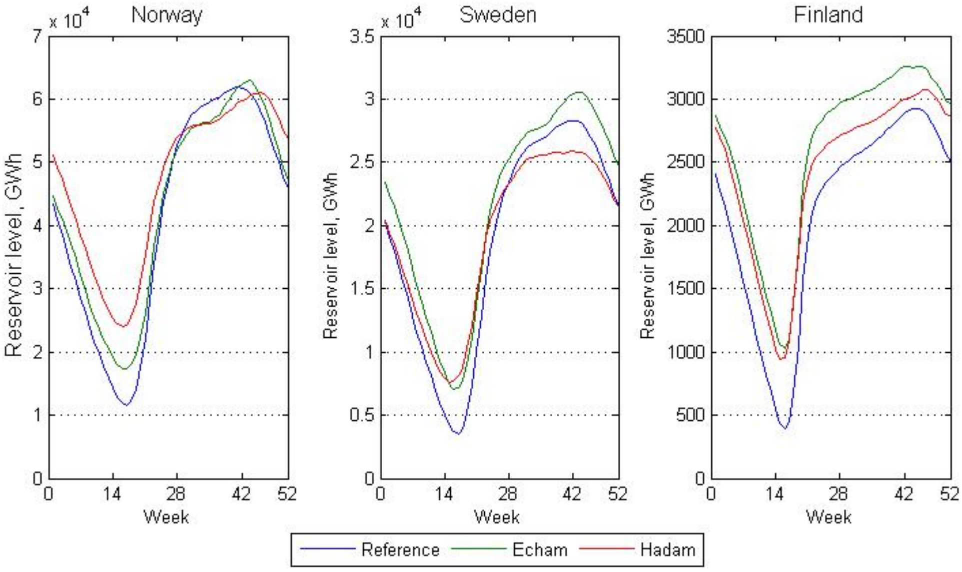


**Figure 4.8: Average weekly reservoir filling over the year (GWh)**

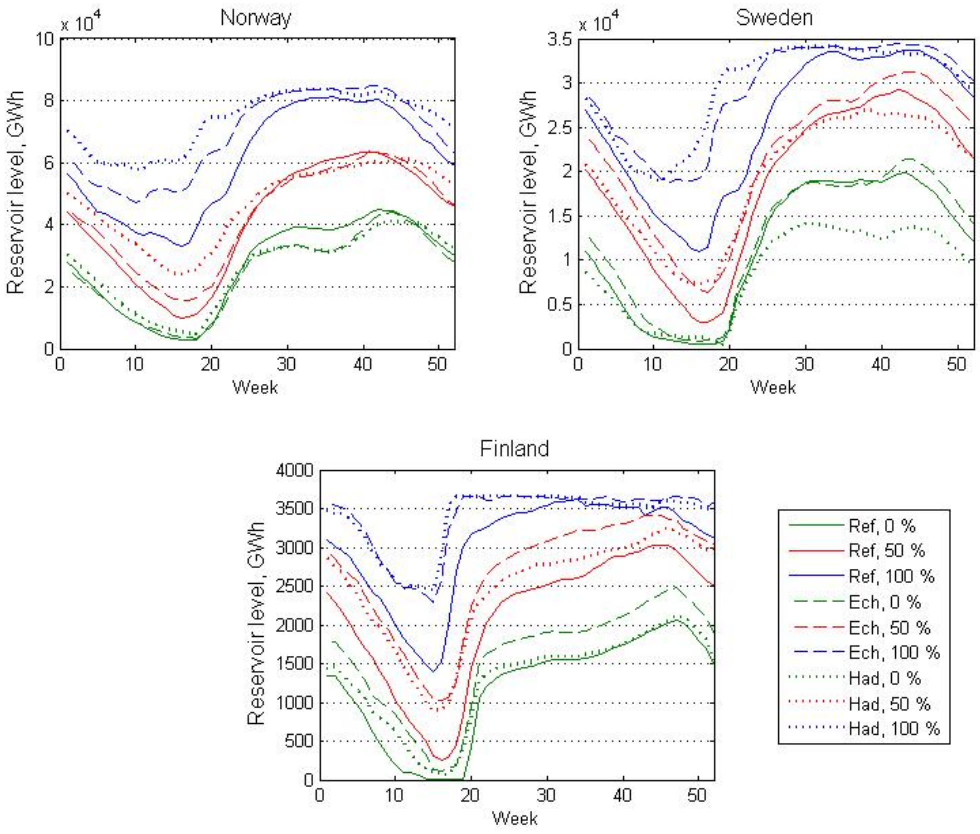


**Figure 4.9: Distribution of reservoir level over the year, represented by percentiles**

## 4.5 Wind power generation

As no wind predictions have been modeled in our analysis, wind power production will be equal in all scenarios. Table 4.10 shows the average annual wind power production for all countries.

**Table 4.10: Average annual wind power production, (TWh/year)**

| | All scenarios | | |
|---|---|---|---|
| | Summer | Winter | Year |
| Norway | 2.3 | 2.9 | 5.2 |
| Sweden | 7.0 | 8.0 | 15.0 |
| Finland | 2.2 | 2.3 | 4.5 |
| Denmark | 7.6 | 8.9 | 16.5 |
| **Sum** | **19.1** | **22.1** | **41.2** |

## 4.6 Thermal power generation

In a situation where more water is available and temperatures go up (i.e. lower demand), hydropower production will substitute parts of the thermal production. For the NordPool area, thermal production decreases with 7 – 8 %.

Table 4.11 shows the average annual thermal power production in TWh per year. Table 4.12 shows the change in thermal production compared to the reference case, in TWh per year, while Table 4.13 shows the equivalent change in percent. Simulation results are in line with expectations as thermal production decreases in all countries.

**Table 4.11: Average annual thermal power production, (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 0.8 | 2.5 | 3.3 | 0.6 | 1.5 | 2.1 | 0.6 | 1.3 | 1.9 |
| Sweden | 47.0 | 46.5 | 93.5 | 45.8 | 46.3 | 92.1 | 45.7 | 46.2 | 91.9 |
| Finland | 31.9 | 37.5 | 69.4 | 28.8 | 33.9 | 62.8 | 29.1 | 33.3 | 62.3 |
| Denmark | 14.6 | 16.5 | 31.1 | 10.9 | 14.7 | 25.5 | 11.5 | 14.2 | 25.7 |
| **Sum** | 94.3 | 103.0 | 197.3 | 86.2 | 96.3 | 182.5 | 86.9 | 94.9 | 181.8 |

**Table 4.12: Absolute change in thermal power production compared to reference case (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -0.2 | -1.0 | -1.2 | -0.2 | -1.2 | -1.4 |
| Sweden | -1.2 | -0.2 | -1.4 | -1.3 | -0.3 | -1.6 |
| Finland | -3.1 | -3.6 | -6.6 | -2.8 | -4.2 | -7.1 |
| Denmark | -3.7 | -1.8 | -5.6 | -3.1 | -2.3 | -5.4 |
| **Sum** | **-8.1** | **-6.7** | **-14.8** | **-7.4** | **-8.1** | **-15.5** |

**Table 4.13: Relative change in thermal power production compared to reference case (%)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -25.0 | -40.0 | -36.4 | -25.0 | -48.0 | -42.4 |
| Sweden | -2.6 | -0.4 | -1.5 | -2.8 | -0.6 | -1.7 |
| Finland | -9.7 | -9.6 | -9.5 | -8.8 | -11.2 | -10.2 |
| Denmark | -25.3 | -10.9 | -18.0 | -21.2 | -13.9 | -17.4 |
| **Sum** | **-8.6** | **-6.5** | **-7.5** | **-7.8** | **-7.9** | **-7.9** |

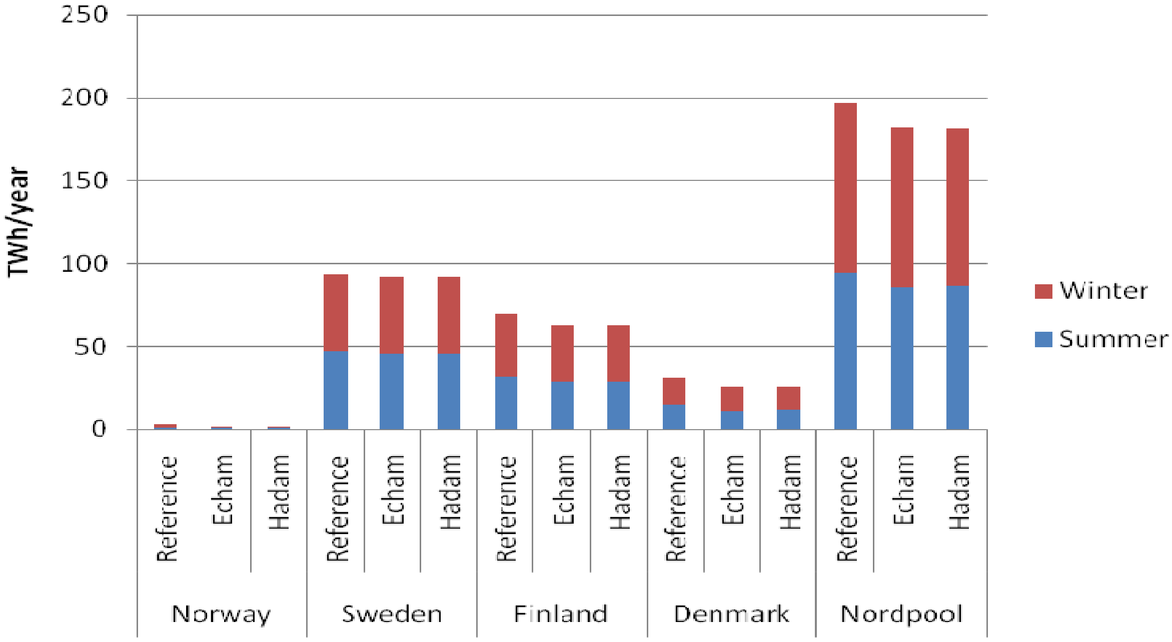


**Figure 4.10: Average annual thermal power production**

## 4.7 Demand

The predicted increase in temperatures is expected to reduce demand. Table 4.14 shows average annual power demand in TWh year for all countries and scenarios.

Table 4.15 shows the change in demand compared to the reference case, in TWh per year, while Table 4.16 shows the equivalent change in percent. Simulation results are in line with expectations. For the NordPool area, demand is reduced with 1.9 % for Echam and 2.5 % for Hadam. The reduction is relatively stronger in the winter than the summer. Demand is reduced for all countries except for Denmark. This is due to temperature predictions for Denmark not being included. The increase in Danish demand stems from transmission loss due to change in power flow patterns. For a more detailed geographical description of demand, see Appendix Table 6.1, Table 6.2 and Table 6.3

**Table 4.14: Average annual power demand, (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 61.5 | 82.0 | 143.6 | 60.4 | 80.6 | 141.0 | 60.2 | 79.7 | 139.8 |
| Sweden | 62.3 | 83.8 | 146.1 | 61.3 | 82.1 | 143.3 | 61.2 | 80.9 | 142.1 |
| Finland | 48.7 | 55.9 | 104.6 | 47.6 | 53.8 | 101.5 | 47.6 | 53.6 | 101.2 |
| Denmark | 18.2 | 20.3 | 38.5 | 18.3 | 20.3 | 38.6 | 18.3 | 20.4 | 38.6 |
| **Nordpool** | **190.7** | **242.1** | **432.8** | **187.6** | **236.8** | **424.4** | **187.2** | **234.6** | **421.8** |

**Table 4.15: Absolute change in power demand compared to reference case (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -1.1 | -1.4 | -2.6 | -1.3 | -2.3 | -3.8 |
| Sweden | -1.0 | -1.7 | -2.8 | -1.1 | -2.9 | -4.0 |
| Finland | -1.1 | -2.1 | -3.1 | -1.1 | -2.3 | -3.4 |
| Denmark | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Nordpool** | **-3.1** | **-5.3** | **-8.4** | **-3.5** | **-7.5** | **-11.0** |

**Table 4.16: Relative change in power demand compared to reference case (%)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -1.8 | -1.7 | -1.8 | -2.1 | -2.8 | -2.6 |
| Sweden | -1.6 | -2.0 | -1.9 | -1.8 | -3.5 | -2.7 |
| Finland | -2.3 | -3.8 | -3.0 | -2.3 | -4.1 | -3.3 |
| Denmark | 0.5 | 0.0 | 0.3 | 0.5 | 0.5 | 0.3 |
| **Nordpool** | **-1.6** | **-2.2** | **-1.9** | **-1.8** | **-3.1** | **-2.5** |

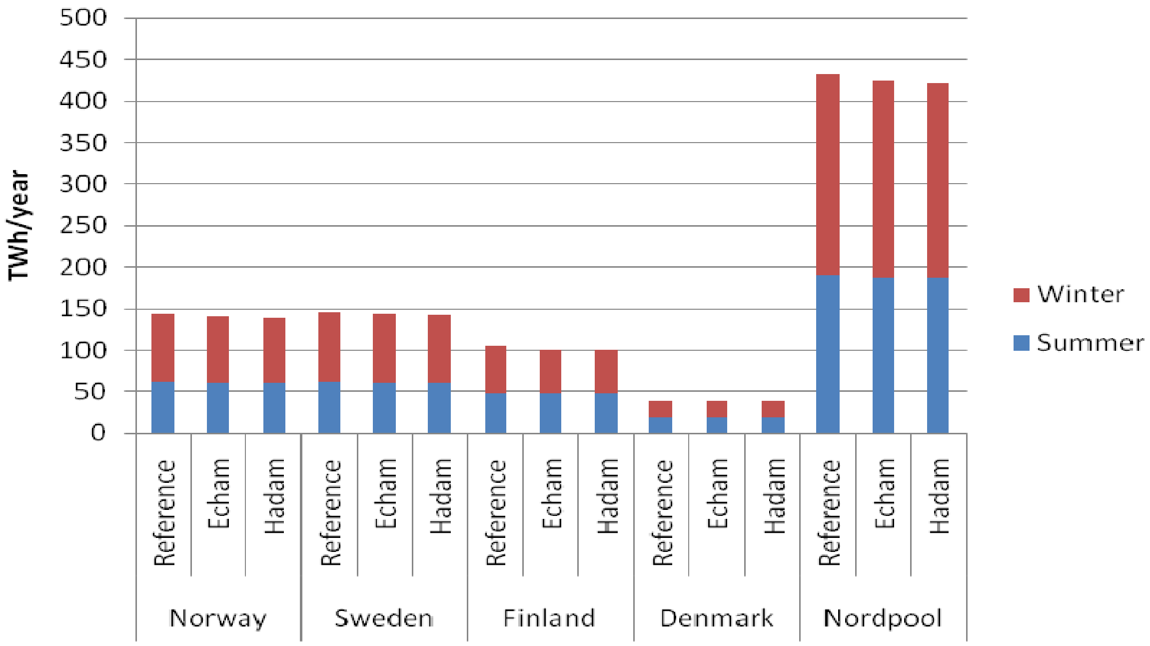


**Figure 4.11: Average annual power demand**

Figure 4.12 shows the average weekly demand over the year. The figure confirms what has already been pointed out. Demand is generally lower in the climatic scenarios, and the decrease is stronger during winter than during summer.

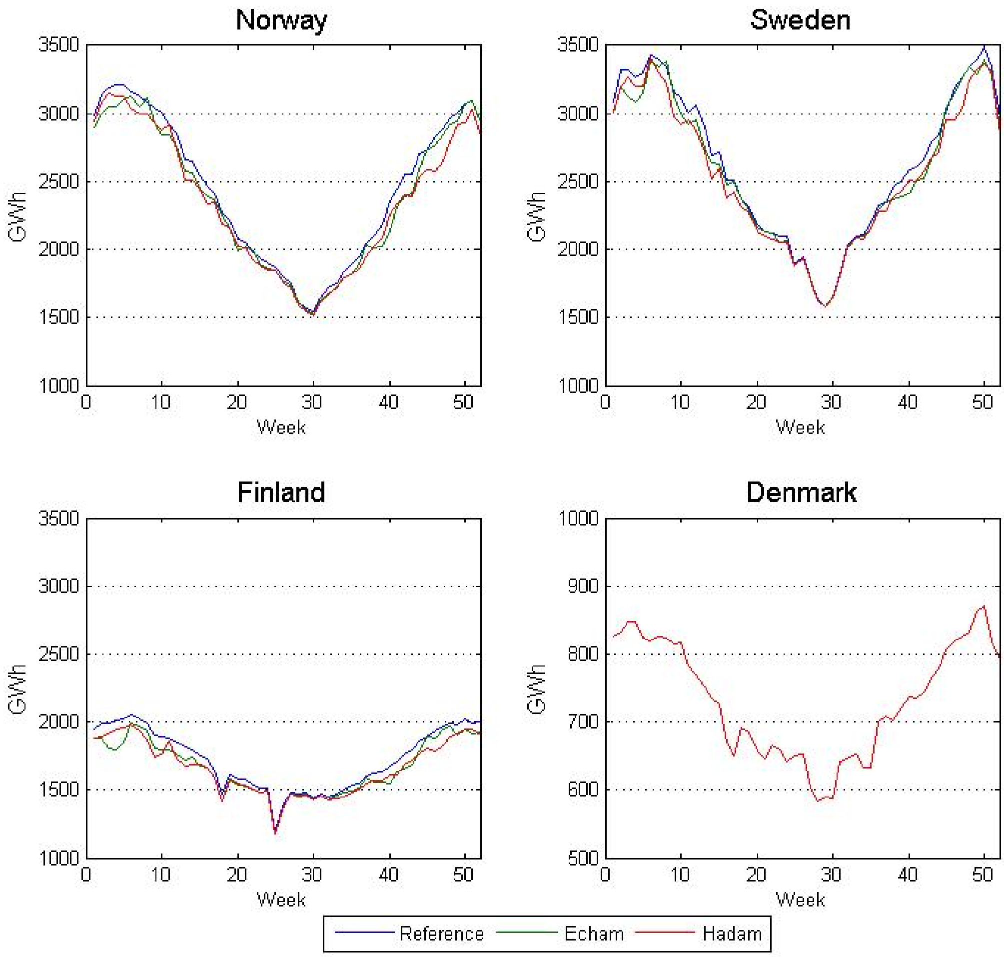


**Figure 4.12: Average weekly demand over the year for firm power**

## 4.8 Prices

Figure 4.13 shows the weekly average spot price over the year for each country in the NordPool area. The country price is the average price for all areas in the respective countries. Simulated prices are heavily affected by assumed fuel- and $CO_2$-prices. We are, however, mostly focusing on the relative change when we compare the different climate scenarios.

Comparing the climatic scenarios to the reference, prices levels drop for the entire year. The Echam price is higher than Hadam during the winter, possibly because of the higher winter inflow in the Hadam prediction. Norway, Sweden and Finland tend to have a larger seasonal variation between summer and winter than Denmark, probably due to Denmark's lack of hydropower combined with its high capacity connection to the German power system.

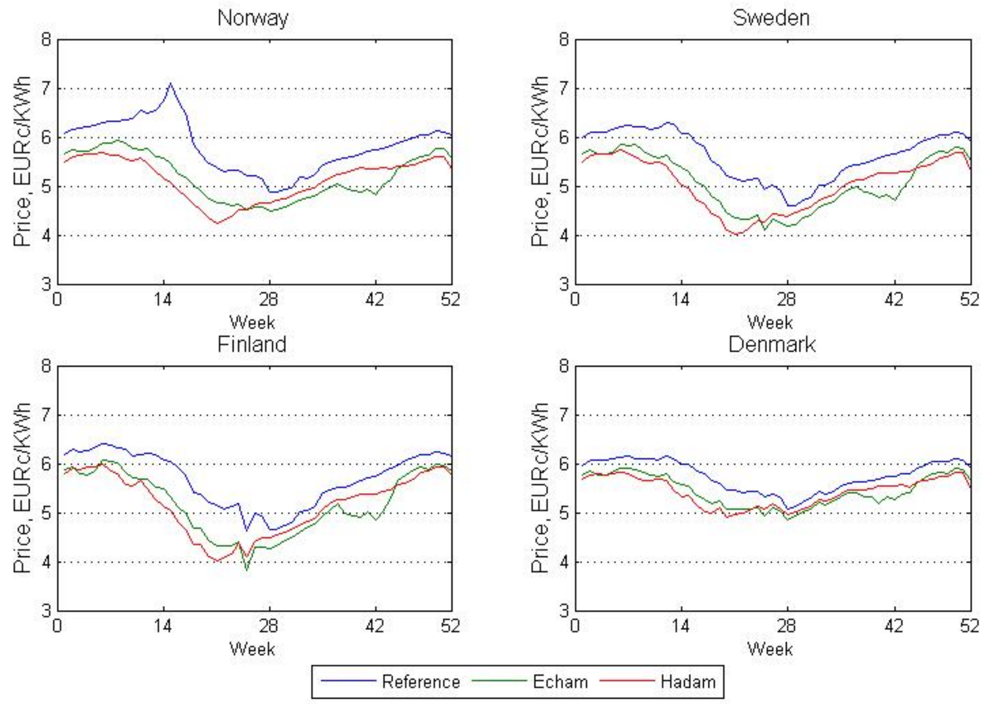


**Figure 4.13: Average weekly spot price over the year**

For better comparison of price levels in the different countries, Figure 4.14 shows the average weekly spot price for all scenarios. In both climatic scenarios, Denmark has a higher price level than the other countries during summer, due to the already mentioned reasons. Sweden and Finland has the lowest average price during summers, while Norway has a slightly higher price.

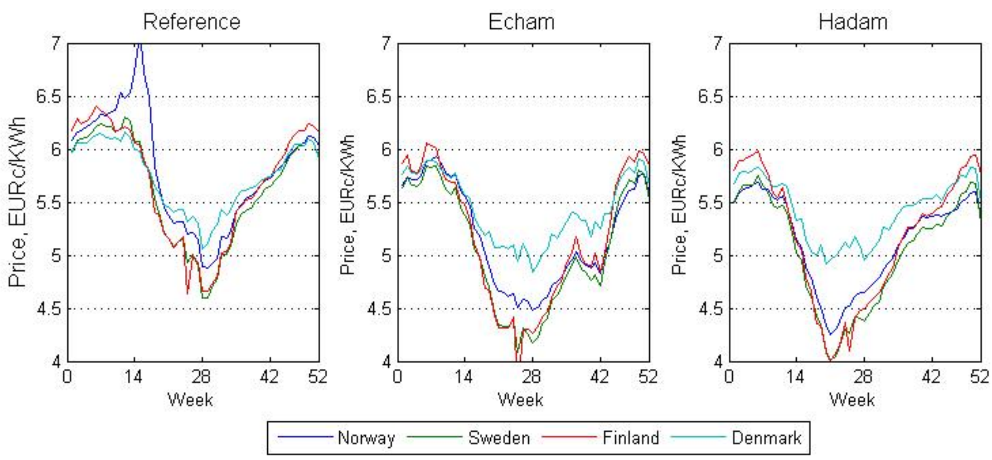


**Figure 4.14: Average weekly spot price over the year**

Figure 4.15 shows the distribution of prices over the year. Comparing the climatic scenarios to the reference, we see that for all countries, the price peaks during low inflow years (100 percentile) are lower. In high inflow years (0 percentile), the period with very low prices tends to increase in duration.

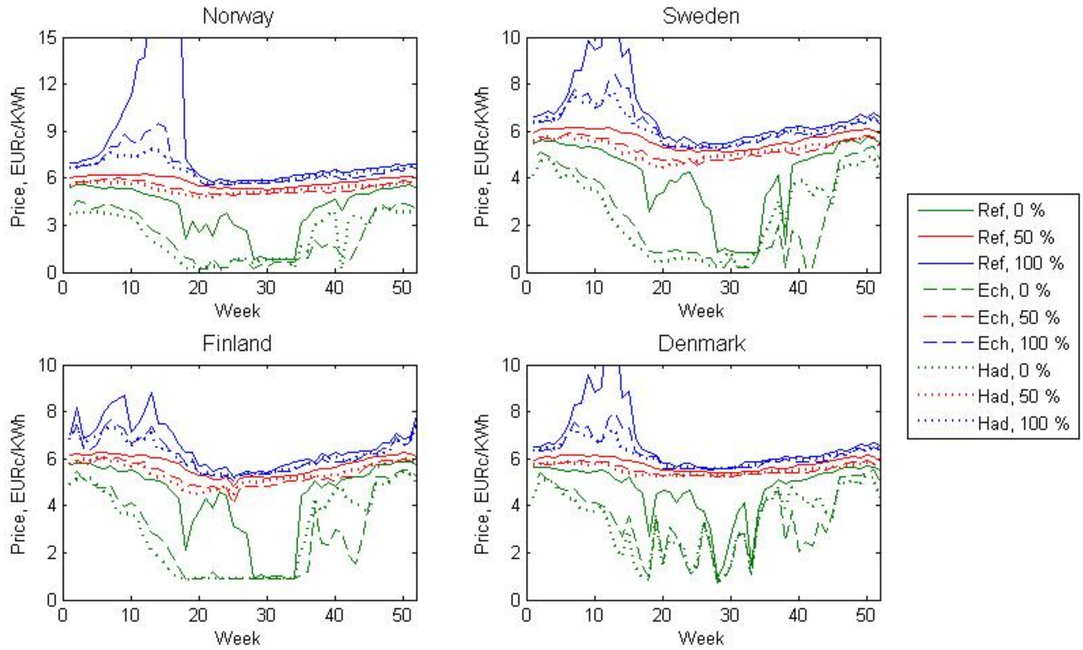


**Figure 4.15: Distribution of weekly spot price over the year**

## 4.9 Exports and imports

**Export and import over the week**[5]

Table 4.17, Table 4.18 and Table 4.19 shows the average annual net export to non-NordPool countries from NordPool countries. Table 4.20 shows the absolute change in TWh comparing the climatic scenarios to the reference case. The increase in net export is simular for both climatic scenarios.

**Table 4.17: Reference, average annual net export to non-NordPool countries (TWh/year)**

| Reference | Day | Night | Weekend | Sum |
|---|---|---|---|---|
| Norway | 8.6 | -2.6 | -2.1 | 3.9 |
| Sweden | 6.8 | -1.8 | -0.2 | 4.8 |
| Denmark | 12.5 | -3.1 | 0.0 | 9.4 |
| **NordPool area** | **27.9** | **-7.5** | **-2.3** | 18.1 |

[5] Finland's connection to Russia has not been included in the presentation of intra-weekly exports. Import from Russia to Finland is modeled as a fixed transaction, which is not controlled by market prices. Accordingly, it will be equal for all scenarios.

**Table 4.18: Echam, average annual net export to non-NordPool countries (TWh/year)**

| Echam | Day | Night | Weekend | Sum |
|---|---|---|---|---|
| Norway | 9.3 | -2.1 | 1.7 | 8.9 |
| Sweden | 7.7 | -1.2 | 2.7 | 9.2 |
| Denmark | 13.3 | -2.3 | 3.1 | 14.1 |
| **NordPool area** | **30.3** | **-5.6** | **7.5** | 32.2 |

**Table 4.19: Hadam, average annual net export to non-NordPool countries (TWh/year)**

| Hadam | Day | Night | Weekend | Sum |
|---|---|---|---|---|
| Norway | 9.4 | -2.3 | 1.5 | 8.6 |
| Sweden | 7.9 | -1.3 | 2.8 | 9.4 |
| Denmark | 13.5 | -2.4 | 3.1 | 14.3 |
| **NordPool area** | **30.8** | **-6.0** | **7.5** | **32.3** |

**Table 4.20: Average annual change in net export to non-NordPool countries compared to reference scenario (TWh/year)**

| | Echam | | | | Hadam | | | |
|---|---|---|---|---|---|---|---|---|
| **Echam** | **Day** | **Night** | **Weekend** | **Sum** | **Day** | **Night** | **Weekend** | **Sum** |
| Norway | 0.7 | 0.5 | 3.8 | 5.0 | 0.8 | 0.3 | 3.6 | 4.7 |
| Sweden | 0.9 | 0.6 | 2.9 | 4.4 | 1.1 | 0.5 | 3.0 | 4.6 |
| Denmark | 0.8 | 0.8 | 3.1 | 4.7 | 1.0 | 0.7 | 3.1 | 4.9 |
| **NordPool area** | **2.4** | **1.9** | **9.8** | **14.1** | **2.9** | **1.5** | **9.8** | **14.2** |

**Export and import over the year**

Table 4.21 shows average annual net exports to non-Nordpool countries, while Table 4.22 shows the absolute change comparing climatic scenarios to the reference. We find that net export increases in both climatic scenarios and that the increase is higher during winter than summer.

**Table 4.21: Average annual net export to non-NordPool countries (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 3.5 | 0.3 | 3.8 | 5.6 | 3.3 | 8.8 | 5.0 | 3.6 | 8.6 |
| Sweden | 4.9 | -0.2 | 4.8 | 6.4 | 2.8 | 9.2 | 6.1 | 3.3 | 9.4 |
| Finland | -4.8 | -5.7 | -10.5 | -4.8 | -5.7 | -10.5 | -4.8 | -5.7 | -10.5 |
| Denmark | 7.2 | 2.1 | 9.4 | 9.1 | 5.0 | 14.1 | 8.6 | 5.7 | 14.3 |
| **Sum** | **10.9** | **-3.4** | **7.5** | **16.3** | **5.4** | **21.7** | 15.0 | 6.9 | 21.8 |

**Table 4.22: Absolute change in net export to Non-Nordpool countries compared to reference (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 2.1 | 3.0 | 5.0 | 1.5 | 3.3 | 4.8 |
| Sweden | 1.5 | 3.0 | 4.4 | 1.2 | 3.5 | 4.6 |
| Finland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Denmark | 1.9 | 2.9 | 4.7 | 1.4 | 3.6 | 4.9 |
| **Sum** | **5.4** | **8.8** | **14.2** | **4.1** | **10.3** | **14.3** |

Table 4.23 shows average annual net exports to other NordPool countries, while Table 4.24 shows the absolute change comparing climatic scenarios to the reference. We find that Sweden is the only net exporter in all scenarios, while the other countries are net importers. In the hydro dominated systems, Norway and Sweden, we find that net exports increase in the climatic scenarios, while for Denmark and Finland net exports decrease.

**Table 4.23: Average annual net export to NordPool countries (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -10.5 | -7.3 | -17.8 | -5.5 | -2.4 | -7.8 | -6.3 | -1.0 | -7.2 |
| Sweden | 16.0 | 8.5 | 24.5 | 18.0 | 9.6 | 27.5 | 18.3 | 9.8 | 28.1 |
| Finland | -2.2 | -4.2 | -6.4 | -3.6 | -5.3 | -9.0 | -4.2 | -5.8 | -10.1 |
| Denmark | -3.3 | 3.0 | -0.3 | -8.8 | -1.9 | -10.7 | -7.8 | -3.0 | -10.8 |
| **Sum** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | 0.0 | 0.0 | 0.0 |

**Table 4.24: Absolute change in net export to Nordpool countries compared to reference (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 5.0 | 4.9 | 10.0 | 4.2 | 6.3 | 10.6 |
| Sweden | 2.0 | 1.1 | 3.0 | 2.3 | 1.3 | 3.6 |
| Finland | -1.4 | -1.1 | -2.6 | -2.0 | -1.6 | -3.7 |
| Denmark | -5.5 | -4.9 | -10.4 | -4.5 | -6.0 | -10.5 |
| **Sum** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** |

Table 4.25 shows the average annual net export for country and season in TWh per year. Table 4.26 show the absolute change in TWh compared to the reference case. Norway and Sweden increase their annual net export while Finland and Denmark decrease their net export. All countries except Finland become net exporters in the climatic scenarios.

Table 4.25: Average annual net export (TWh/year)

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -7.0 | -7.0 | -14.0 | 0.1 | 0.9 | 1.0 | -1.2 | 2.6 | 1.4 |
| Sweden | 20.9 | 8.4 | 29.3 | 24.4 | 12.3 | 36.8 | 24.4 | 13.1 | 37.5 |
| Finland | -7.0 | -9.9 | -16.9 | -8.4 | -11.0 | -19.5 | -9.0 | -11.5 | -20.6 |
| Denmark | 4.0 | 5.1 | 9.1 | 0.2 | 3.2 | 3.4 | 0.8 | 2.7 | 3.5 |
| **Sum** | 10.9 | -3.4 | 7.5 | 16.3 | 5.4 | 21.7 | 15.0 | 6.9 | 21.8 |

Table 4.26: Absolute change in net export compared to reference case (TWh/year)

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 7.1 | 7.9 | 15.0 | 5.8 | 9.6 | 15.4 |
| Sweden | 3.5 | 3.9 | 7.5 | 3.5 | 4.7 | 8.2 |
| Finland | -1.4 | -1.1 | -2.6 | -2.0 | -1.6 | -3.7 |
| Denmark | -3.8 | -1.9 | -5.7 | -3.2 | -2.4 | -5.6 |
| **Sum** | **5.4** | **8.8** | **14.2** | **4.1** | **10.3** | **14.3** |

## 4.10 Energy balances

Table 4.27, Table 4.28 and Table 4.29 shows the annual average annual energy balance for each country, in TWh per year. These tables provide an overview of the already presented results. To reiterate, main findings are increased hydropower production, decreased thermal power production, and decreased demand, except Denmark, for all countries in the climate scenarios. Net import decreases for all countries but Finland. Wind forecasts have not been modeled, so the power production from wind remains equal for all scenarios.

Table 4.27: Reference, average annual energy balance (TWh/year)

| **Reference** | **Hydro** | **Thermal** | **Wind** | **Net Import** | **Demand** |
|---|---|---|---|---|---|
| Norway | 121.1 | 3.3 | 5.2 | 14.0 | 143.6 |
| Sweden | 66.9 | 93.5 | 15.0 | -29.3 | 146.1 |
| Denmark | 0.0 | 31.1 | 16.5 | -9.1 | 38.5 |
| Finland | 13.8 | 69.4 | 4.5 | 16.9 | 104.6 |
| **NordPool** | **201.8** | **197.3** | **41.2** | **-7.5** | **432.8** |

Table 4.28: Echam, average annual energy balance (TWh/year)

| **Echam** | **Hydro** | **Thermal** | **Wind** | **Net Import** | **Demand** |
|---|---|---|---|---|---|
| Norway | 134.7 | 2.1 | 5.2 | -1.0 | 141.0 |
| Sweden | 73.0 | 92.1 | 15.0 | -36.8 | 143.3 |
| Denmark | 0.0 | 25.5 | 16.5 | -3.4 | 38.6 |
| Finland | 14.7 | 62.8 | 4.5 | 19.5 | 101.5 |
| **NordPool** | **222.5** | **182.5** | **41.2** | **-21.7** | **424.4** |

**Table 4.29: Hadam, average annual energy balance (TWh/year)**

| Hadam | Hydro | Thermal | Wind | Net Import | Demand |
|---|---|---|---|---|---|
| Norway | 134.2 | 1.9 | 5.2 | -1.4 | 139.8 |
| Sweden | 72.6 | 91.9 | 15.0 | -37.5 | 142.1 |
| Denmark | 0.0 | 25.7 | 16.5 | -3.5 | 38.6 |
| Finland | 13.8 | 62.3 | 4.5 | 20.6 | 101.2 |
| **NordPool** | **220.7** | **181.8** | **41.2** | **-21.8** | **421.8** |

## 4.11 $CO_2$-emissions

Table 4.30 shows average annual $CO_2$-emission from power production in million tonne per year. Table 4.31 and Table 4.32 show the absolute and relative change in $CO_2$-emissions comparing the climatic scenarios to the reference. The upper part of the table shows $CO_2$-emission directly from the power producing units in each country. The lower part shows $CO_2$-emission due to Nordic import from European power producers and the reduction in emission in Europe due to export from the NordPool countries. The “Sum, adjusted for Europe” is the total emission caused by the NordPool power system, when also emission reductions in Europe are taken into account. The results reveal that emissions for the total system are reduced with 57 % in the climatic scenarios. The largest components are reductions in Finnish emissions and reductions from less import from Europe combined with the substitution effect from more export to Europe.

The simulated reductions in the European power system should be interpreted with caution. Our estimates show only the estimated short run direct effects from changed climatic conditions in the Nordic power system. The European $CO_2$-quota market is based on a fixed annual total emission roof. If the Nordic region reduces its $CO_2$ emission one would expect the price of quotas to go down and opens up for new entrants, which become profitable with the reduced $CO_2$ price. New $CO_2$ emitters will consequently substitute the reduced Nordic $CO_2$ emission.

However, taking into account a political dimension, a long-term reduction in $CO_2$-quota price might signal to regulators that the total emission roof is eligible for reduction. Such a reduction can thus give a valid long run effect from local emission reduction on total emissions.

**Table 4.30: Average annual CO2-emission from power production (Mtonne/year)**

| | Reference | Echam | Hadam |
|---|---|---|---|
| Norway | 1.4 | 1.1 | 1.0 |
| Sweden | 5.1 | 4.4 | 4.4 |
| Finland | 14.7 | 9.1 | 8.7 |
| Denmark | 24.0 | 20.0 | 20.1 |
| **Sum** | **45.2** | **34.6** | **34.2** |
| Import from Europe | 14.7 | 8.5 | 8.7 |
| Export to Europe | -16.9 | -24.5 | -24.6 |
| **Sum, adjusted for Europe** | **43.0** | **18.5** | **18.4** |

**Table 4.31: Absolute change in $CO_2$-emission from power production compared to reference case (Mtonne/year)**

| | Echam | Hadam |
|---|---|---|
| Norway | -0.3 | -0.4 |
| Sweden | -0.7 | -0.7 |
| Finland | -5.6 | -6.0 |
| Denmark | -4.0 | -3.9 |
| **Sum** | **-10.6** | **-11.0** |
| Import from Europe | -6.2 | -6.0 |
| Export to Europe | -7.6 | -7.7 |
| **Sum, adjusted for Europe** | **-24.5** | **-24.6** |

**Table 4.32: Relative change in CO2-emission from power production compared to reference case (%)**

| | Echam | Hadam |
|---|---|---|
| Norway | -21.4 | -28.6 |
| Sweden | -13.7 | -13.7 |
| Finland | -38.1 | -40.8 |
| Denmark | -16.7 | -16.3 |
| **Sum** | **-23.5** | **-24.3** |
| Import from Europe | -42.2 | -40.8 |
| Export to Europe | 45.0 | 45.6 |
| **Sum, adjusted for Europe** | **-57.0** | **-57.2** |

# 5 Summary and concluding remarks

This study has examined and quantified effects on an assumed Nordic power system in 2020, due to changes in climatic conditions. Predicted climatic variables include inflow and temperature for the period 2020 to 2050.

The predicted average annual inflow represents an increase of 12-13 % compared to current conditions. A significant part of this increase stems from more inflow during the winter season. The predicted average daily temperature is expected to increase with 1-2 Celsius degrees. Also here we find that temperatures increase more during the winter.

Hydropower production is expected to increase with 10 % for the NordPool area in total. No prominent temporal changes have been found.

Spillage is expected to increase with 35 – 45 % for the NordPool area in total. Here we find that spillage during winter is the major component in the increase.

Reservoir handling is expected to change towards less variation in reservoir level over the year. The main component in this comes from the tendency that reservoirs will be less empty during late winter/spring.

Annual average thermal production is expected to decrease with 6-7 % for the NordPool area in total. No major seasonal patterns have been found, but there is a tendency for thermal production to decrease most during summers.

Annual average demand decreases with 2 - 2.5 % for the NordPool area. The decrease is relatively stronger during winter than summer due to the stronger reduction in winter temperatures.

Electricity spot prices go down in all countries in the climatic scenarios. The reduction in Denmark is relatively small compared to the other countries, due to its strong connection to the European market and its lack of hydropower generation. The probability for high prices during late winter is reduced for all countries and the probability for long periods with low prices during summer increase.

Net export increases for all countries in the climatic scenarios. A decomposition shows that all countries increase their net export to Europe, while the hydro dominated systems (Norway and Sweden) increase their net export to other NordPool countries. Total net export increases for the hydro dominated systems while Denmark and Finland reduce their total net export. All countries but Finland are net exporters in the climatic scenarios.

Due to the reduction in thermal power production, all countries contribute to a reduced total $CO_2$ emission in the Nordic region. The increased hydro production gives more export to continental Europe. This export will reduce thermal power production, which leads to reduced $CO_2$ emission in continental Europe. The total reduction (NordPool area plus continental Europe) is approximately 25 Mtonne per year, or relatively, 60 % compared to the reference.

# 6 Appendix

## 6.1 Power system

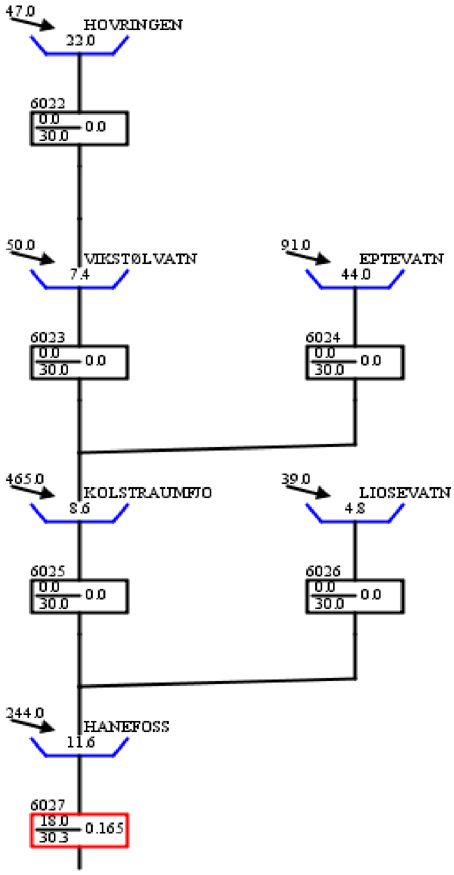


**Figure 6.1: Example subsystem of hydropower modules**

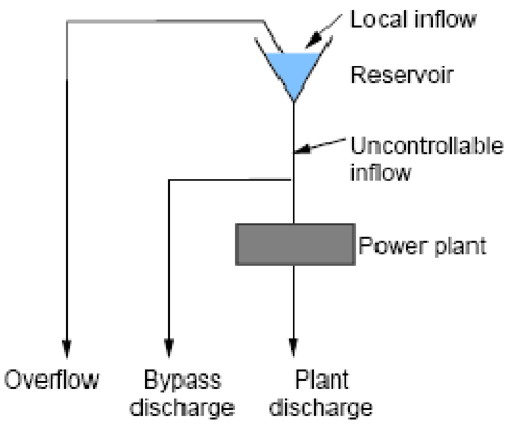


**Figure 6.2: Hydropower module properties**

## 6.2 Inflow

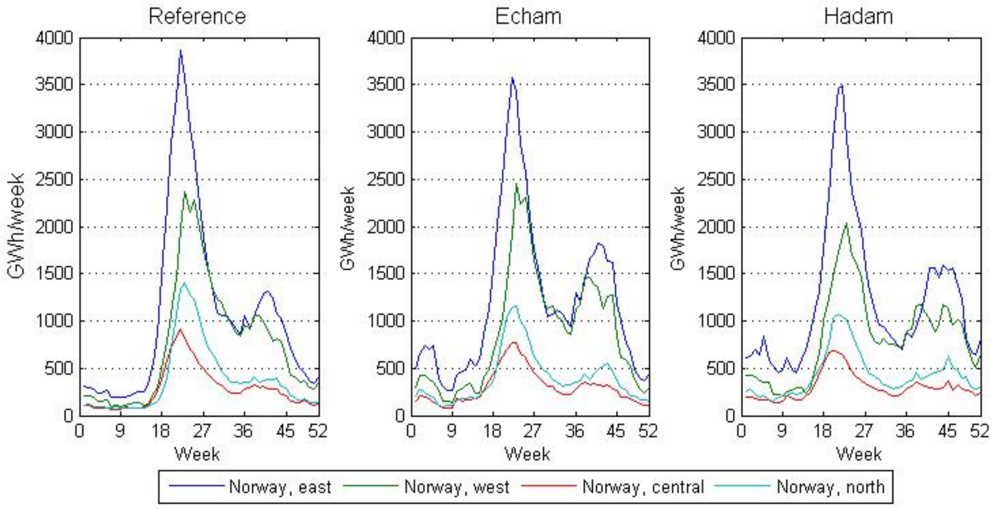


**Figure 6.3: Inflow over the year, Norwegian areas**

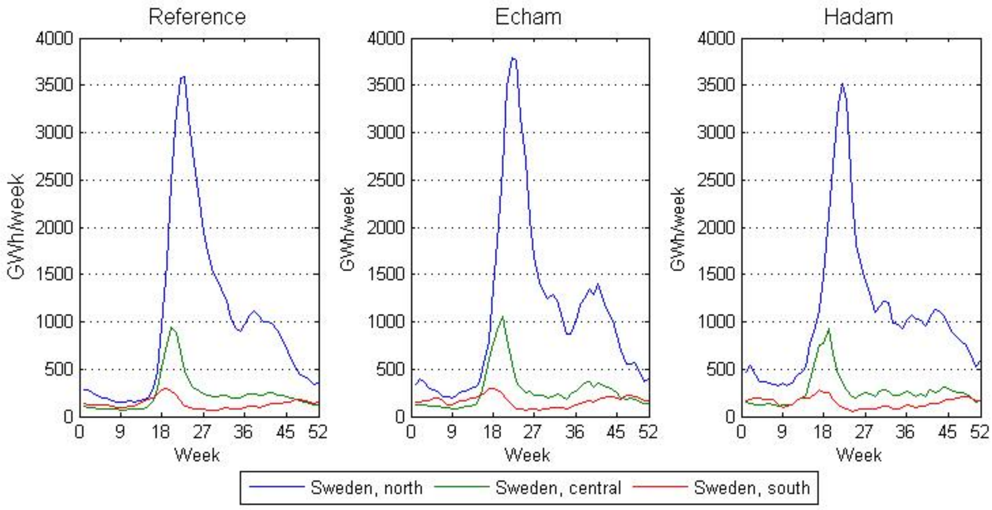


**Figure 6.4: Inflow over the year, Swedish areas**

## 6.3 Reservoir handling

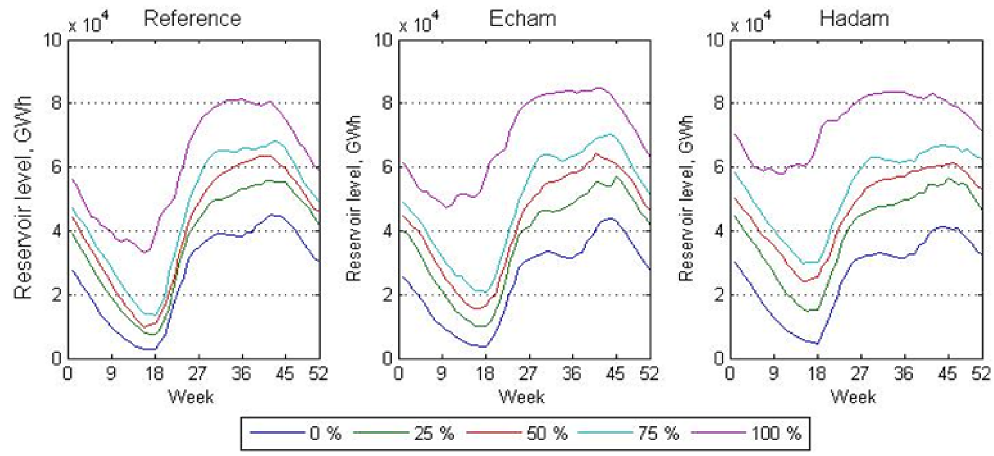


**Figure 6.5: Norway, distribution of reservoir filling levels over the year**

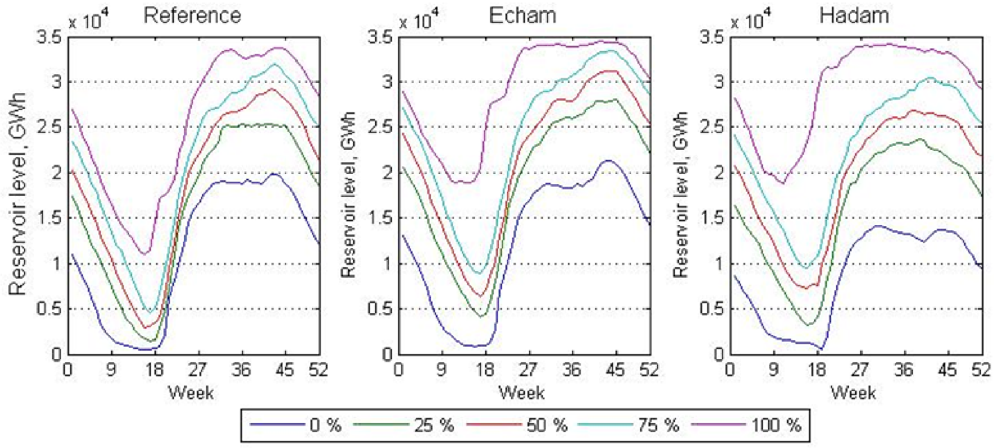


**Figure 6.6: Sweden, distribution of reservoir filling levels over the year**

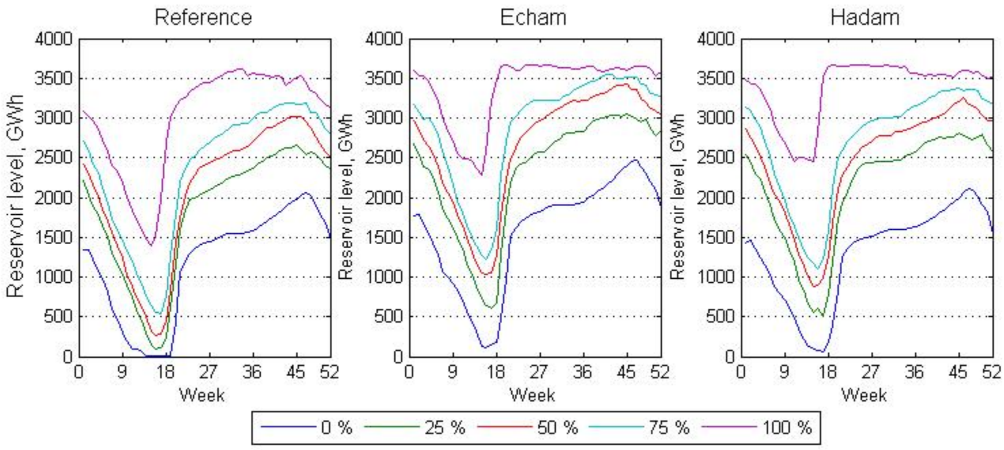


**Figure 6.7: Finland, distribution of reservoir filling levels over the year**

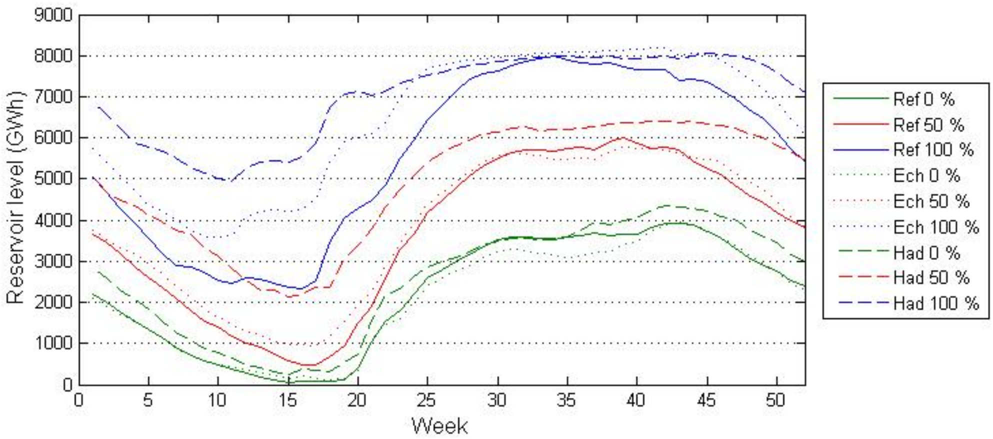


**Figure 6.8: Central Norway, distribution of reservoir filling levels over the year**

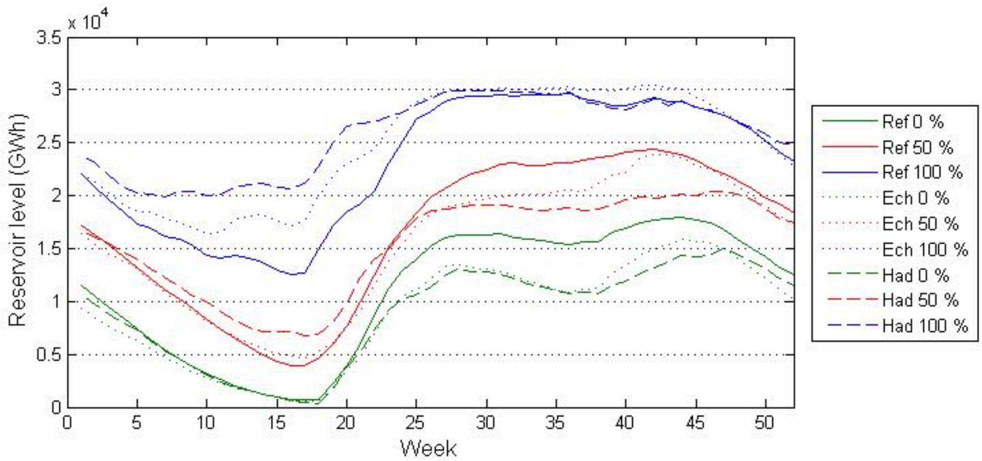


**Figure 6.9: Eastern Norway, distribution of reservoir filling levels over the year**

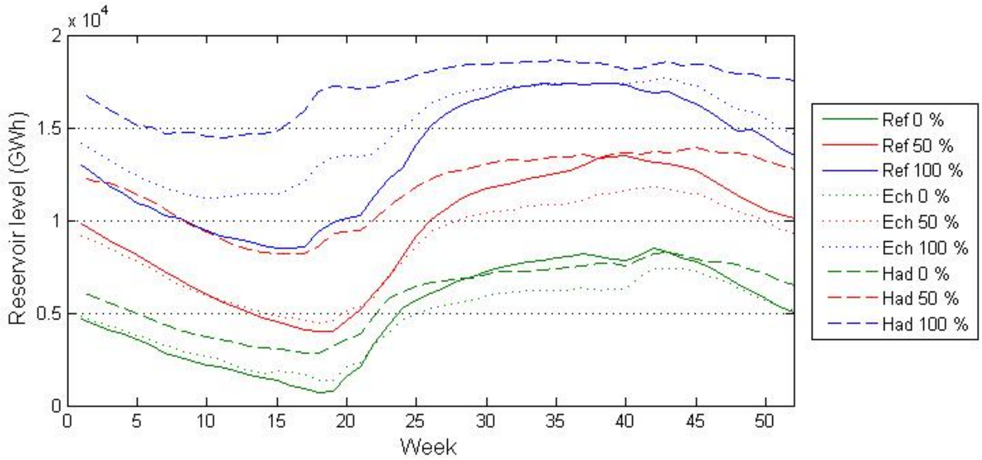


**Figure 6.10: Northern Norway, distribution of reservoir filling levels over the year**

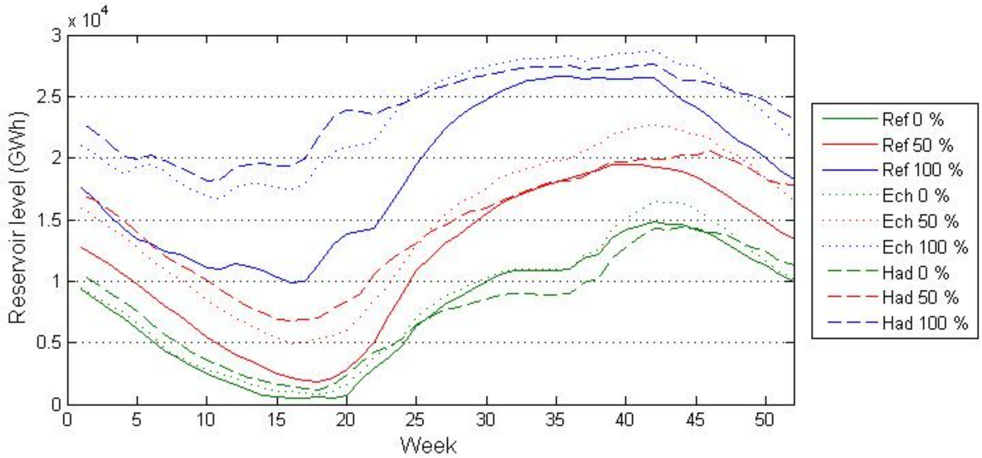


**Figure 6.11: Western Norway, distribution of reservoir filling levels over the year**

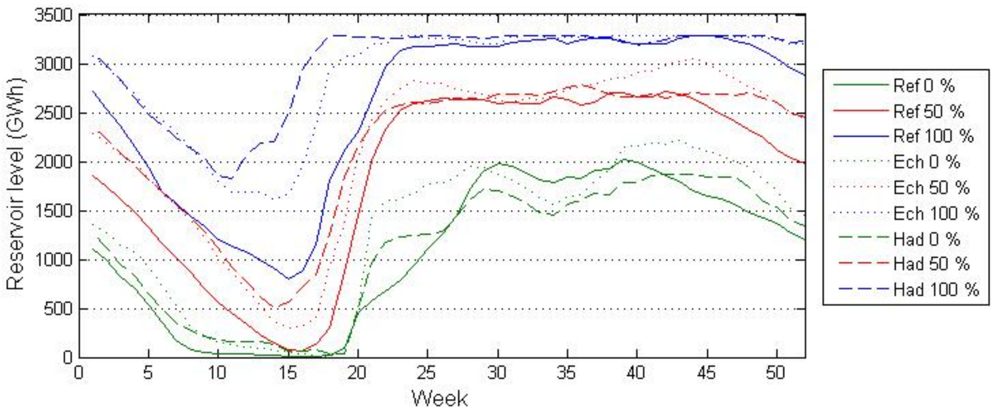


**Figure 6.12: Central Sweden, distribution of reservoir filling levels over the year**

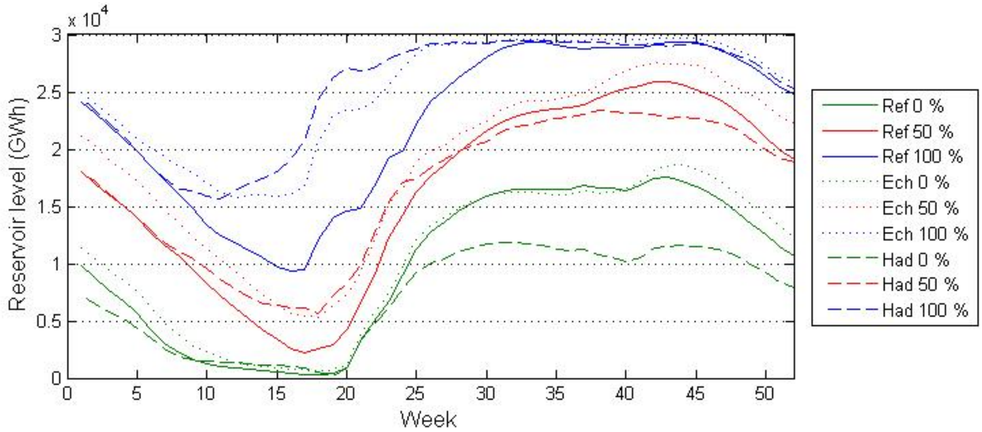


**Figure 6.13: Northern Sweden, distribution of reservoir filling levels over the year**

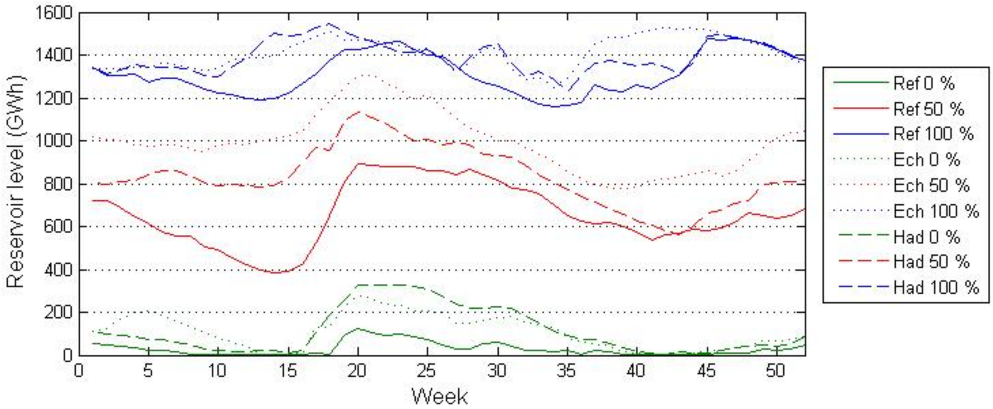


**Figure 6.14: Southern Sweden, distribution of reservoir filling levels over the year**

## 6.4 Demand

**Table 6.1: Average annual firm power demand (TWh/year)**

| | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | 26.9 | 39.7 | 66.6 | 26.1 | 38.6 | 64.6 | 26.2 | 38.3 | 64.5 |
| West Norway | 10.2 | 12.3 | 22.5 | 10.0 | 12.0 | 22.0 | 10.0 | 12.0 | 22.0 |
| Central Norway | 10.4 | 13.2 | 23.6 | 10.1 | 12.9 | 23.0 | 10.1 | 12.9 | 23.0 |
| North Norway | 6.5 | 8.4 | 14.9 | 6.3 | 8.1 | 14.4 | 5.9 | 7.4 | 13.3 |
| **Sum Norway** | **54.0** | **73.5** | **127.5** | **52.4** | **71.6** | **124.0** | **52.3** | **70.6** | **122.8** |
| | | | | | | | | | |
| North Sweden | 11.2 | 14.9 | 26.1 | 11.0 | 14.6 | 25.5 | 10.9 | 14.4 | 25.3 |
| Central Sweden | 36.5 | 48.7 | 85.2 | 35.8 | 47.5 | 83.3 | 35.8 | 46.8 | 82.6 |
| South Sweden | 11.2 | 14.9 | 26.1 | 11.0 | 14.6 | 25.5 | 11.0 | 14.3 | 25.3 |
| **Sum Sweden** | **58.9** | **78.5** | **137.3** | **57.8** | **76.6** | **134.4** | **57.7** | **75.5** | **133.2** |
| | | | | | | | | | |
| East Denmark | 7.0 | 8.3 | 15.3 | 7.0 | 8.3 | 15.3 | 7.0 | 8.3 | 15.3 |
| West Denmark | 11.0 | 11.8 | 22.8 | 11.0 | 11.8 | 22.8 | 11.0 | 11.8 | 22.8 |
| **Sum Denmark** | **18.0** | **20.1** | **38.1** | **18.0** | **20.1** | **38.1** | **18.0** | **20.1** | **38.1** |
| | | | | | | | | | |
| **Finland** | 41.7 | 48.3 | 90.0 | 40.6 | 46.2 | 86.8 | 40.6 | 46.0 | 86.6 |
| | | | | | | | | | |
| **Nord Pool area** | **172.6** | **220.4** | **393.0** | **168.8** | **214.6** | **383.4** | **168.5** | **212.2** | **380.7** |

**Table 6.2: Absolute change in firm power demand compared to reference case (TWh/year)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | -0.8 | -1.1 | -2.0 | -0.7 | -1.4 | -2.1 |
| West Norway | -0.2 | -0.3 | -0.5 | -0.2 | -0.3 | -0.5 |
| Central Norway | -0.3 | -0.3 | -0.6 | -0.3 | -0.3 | -0.6 |
| North Norway | -0.2 | -0.3 | -0.5 | -0.6 | -1.0 | -1.6 |
| **Sum Norway** | -1.6 | -1.9 | -3.5 | -1.7 | -2.9 | -4.7 |
| | | | | | | |
| North Sweden | -0.2 | -0.3 | -0.6 | -0.3 | -0.5 | -0.8 |
| Central Sweden | -0.7 | -1.2 | -1.9 | -0.7 | -1.9 | -2.6 |
| South Sweden | -0.2 | -0.3 | -0.6 | -0.2 | -0.6 | -0.8 |
| **Sum Sweden** | -1.1 | -1.9 | -2.9 | -1.2 | -3.0 | -4.1 |
| | | | | | | |
| **Finland** | -1.1 | -2.1 | -3.2 | -1.1 | -2.3 | -3.4 |
| | | | | | | |
| **Nord Pool area** | -3.8 | -5.8 | -9.6 | -4.1 | -8.2 | -12.3 |

**Table 6.3: Relative change in firm power demand compared to reference case (%)**

| | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| **Area** | Summer | Winter | Year | Summer | Winter | Year |
| East Norway | -3.0 | -2.8 | -3.0 | -2.6 | -3.5 | -3.2 |
| West Norway | -2.0 | -2.4 | -2.2 | -2.0 | -2.4 | -2.2 |
| Central Norway | -2.9 | -2.3 | -2.5 | -2.9 | -2.3 | -2.5 |
| North Norway | -3.1 | -3.6 | -3.4 | -9.2 | -11.9 | -10.7 |
| **Sum Norway** | -3.0 | -2.6 | -2.7 | -3.1 | -3.9 | -3.7 |
| | | | | | | |
| North Sweden | -1.8 | -2.0 | -2.3 | -2.7 | -3.4 | -3.1 |
| Central Sweden | -1.9 | -2.5 | -2.2 | -1.9 | -3.9 | -3.1 |
| South Sweden | -1.8 | -2.0 | -2.3 | -1.8 | -4.0 | -3.1 |
| **Sum Sweden** | -1.9 | -2.4 | -2.1 | -2.0 | -3.8 | -3.0 |
| | | | | | | |
| **Finland** | -2.6 | -4.3 | -3.6 | -2.6 | -4.8 | -3.8 |
| | | | | | | |
| **Nord Pool area** | -2.2 | -2.6 | -2.4 | -2.4 | -3.7 | -3.1 |

## 6.5 Prices

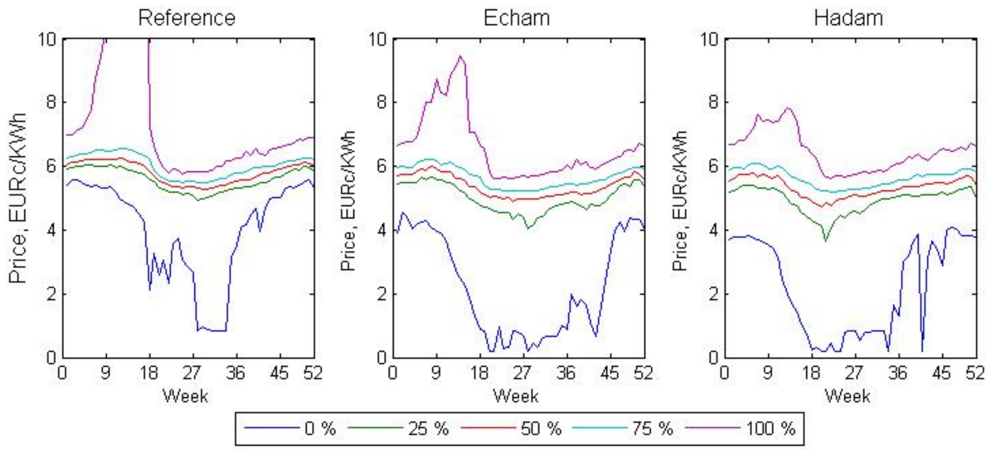


**Figure 6.15: Norway, distribution of weekly prices over the year**

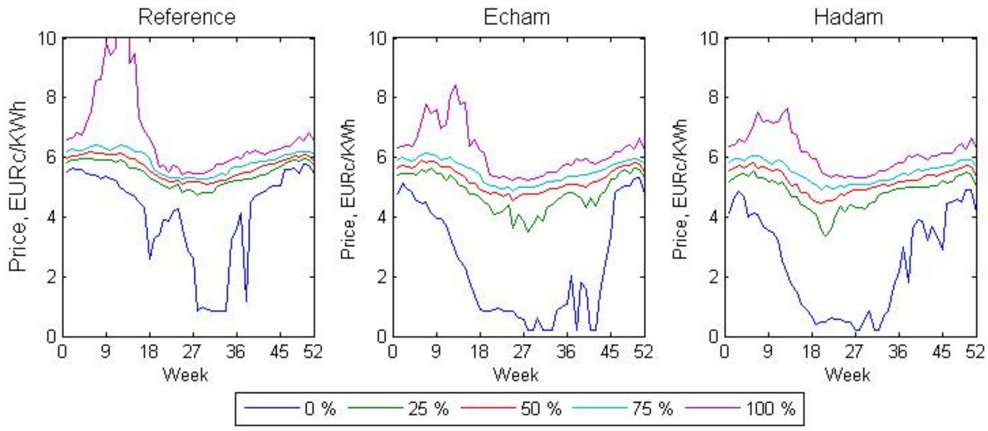


**Figure 6.16: Sweden, distribution of weekly prices over the year**

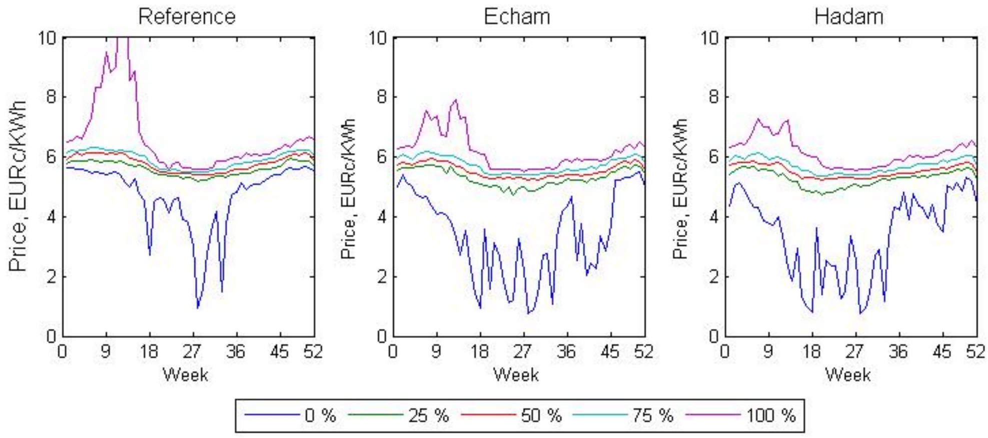


**Figure 6.17: Denmark, distribution of weekly prices over the year**

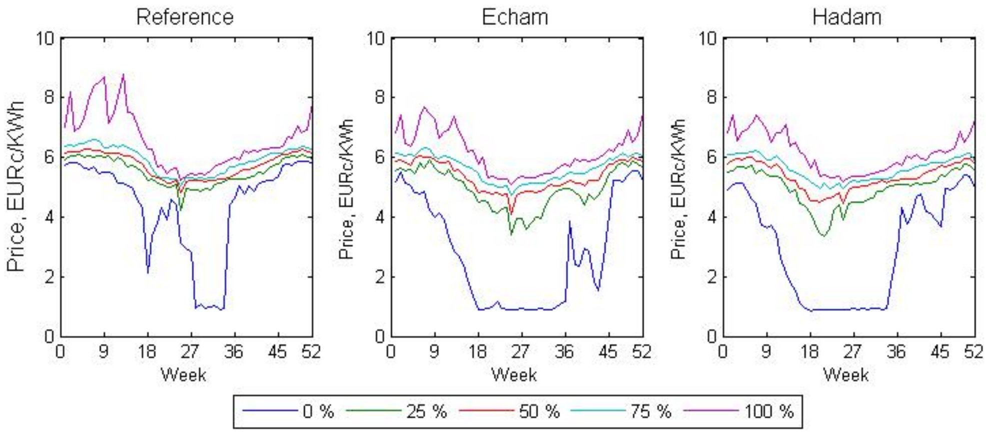


**Figure 6.18: Finland, distribution of weekly prices over the year**

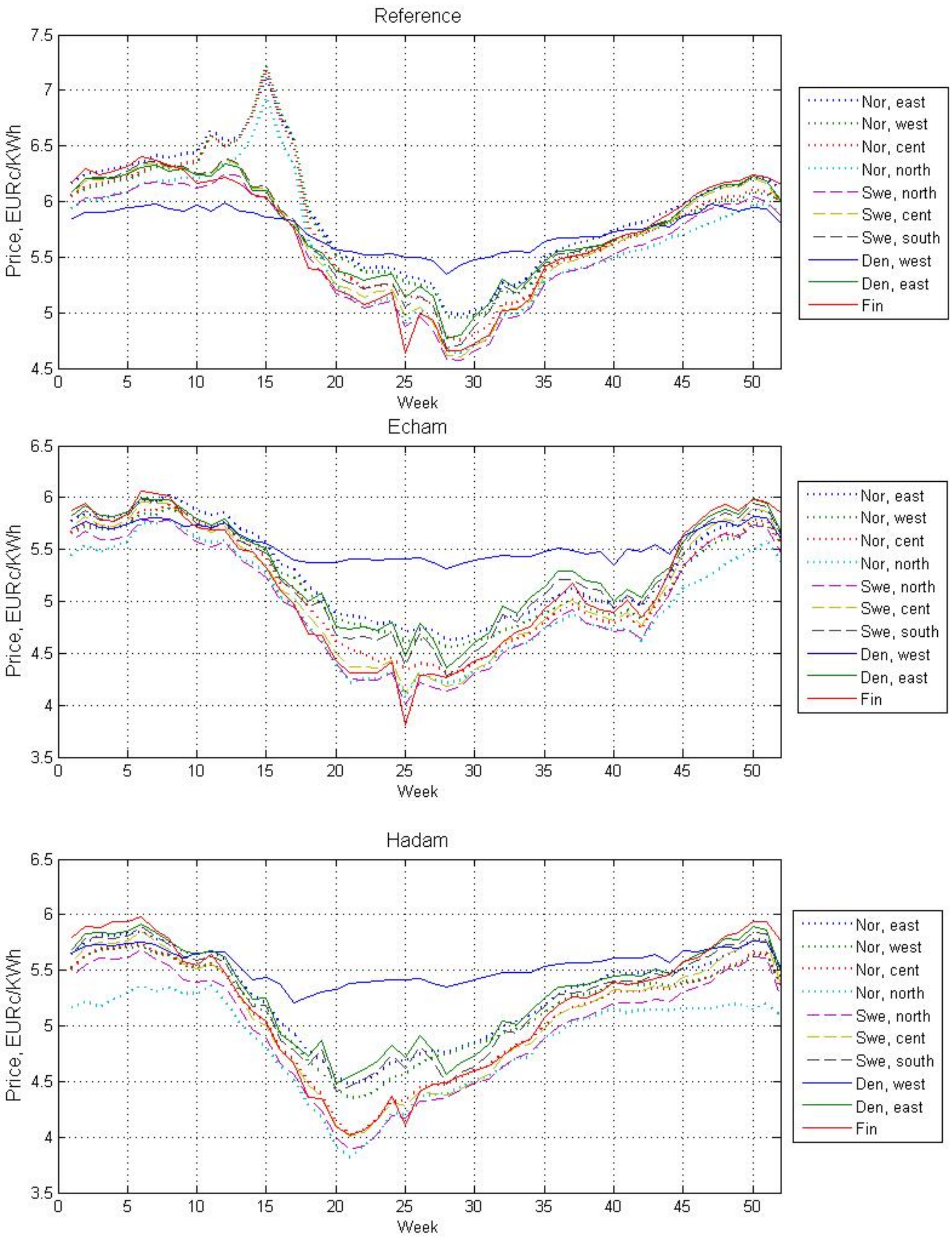


**Figure 6.19: Average spot price, (EURc/kWh)**

## 6.6 Exports imports

**Table 6.4: Reference, average annual export and import to/from non-NordPool countries (TWh/year)**

| Reference | | Export | | | | Import | | | |
|---|---|---|---|---|---|---|---|---|---|
| From | To | Day | Night | Weekend | Sum | Day | Night | Weekend | Sum |
| Norway | Germany | 6.0 | 0.1 | 0.4 | 6.4 | 0.1 | 1.9 | 2.0 | 4.0 |
| Norway | Netherlands | 2.7 | 0.0 | 0.1 | 2.8 | 0.0 | 0.8 | 0.5 | 1.4 |
| Denmark | Germany | 12.6 | 0.1 | 1.1 | 13.8 | 0.1 | 3.3 | 1.1 | 4.4 |
| Sweden | Germany | 2.4 | 0.1 | 0.5 | 3.0 | 0.1 | 0.7 | 0.5 | 1.4 |
| Sweden | Poland | 2.4 | 0.1 | 0.5 | 3.0 | 0.1 | 0.7 | 0.5 | 1.4 |
| Sweden | Baltics | 2.4 | 0.1 | 0.5 | 3.0 | 0.1 | 0.7 | 0.5 | 1.4 |
| **Sum** | | **28.5** | **0.5** | **3.1** | **32.0** | **0.5** | **8.1** | **5.1** | **14.0** |

**Table 6.5: Echam, average annual export and import to/from non-NordPool countries (TWh/year)**

| Echam | | Export | | | | Import | | | |
|---|---|---|---|---|---|---|---|---|---|
| From | To | Day | Night | Weekend | Sum | Day | Night | Weekend | Sum |
| Norway | Germany | 6.3 | 0.2 | 1.7 | 8.2 | 0.0 | 1.7 | 0.4 | 2.1 |
| Norway | Netherlands | 3.0 | 0.1 | 0.4 | 3.5 | 0.0 | 0.7 | 0.1 | 0.8 |
| Denmark | Germany | 13.4 | 0.4 | 3.2 | 17.0 | 0.0 | 2.7 | 0.2 | 2.9 |
| Sweden | Germany | 2.6 | 0.2 | 1.0 | 3.8 | 0.1 | 0.6 | 0.1 | 0.8 |
| Sweden | Poland | 2.6 | 0.2 | 1.0 | 3.8 | 0.1 | 0.6 | 0.1 | 0.8 |
| Sweden | Baltics | 2.6 | 0.2 | 1.0 | 3.8 | 0.1 | 0.6 | 0.1 | 0.8 |
| **Sum** | | **30.5** | **1.3** | **8.3** | **40.1** | **0.3** | **6.9** | **1.0** | **8.2** |

**Table 6.6: Hadam, average annual export and import to/from non-NordPool countries (TWh/year)**

| Hadam | | Export | | | | Import | | | |
|---|---|---|---|---|---|---|---|---|---|
| From | To | Day | Night | Weekend | Sum | Day | Night | Weekend | Sum |
| Norway | Germany | 6.4 | 0.2 | 1.6 | 8.1 | 0.0 | 1.8 | 0.5 | 2.3 |
| Norway | Netherlands | 3.1 | 0.0 | 0.5 | 3.6 | 0.0 | 0.7 | 0.1 | 0.8 |
| Denmark | Germany | 13.6 | 0.3 | 3.3 | 17.2 | 0.0 | 2.7 | 0.2 | 2.9 |
| Sweden | Germany | 2.7 | 0.2 | 1.1 | 3.9 | 0.0 | 0.6 | 0.1 | 0.7 |
| Sweden | Poland | 2.7 | 0.2 | 1.1 | 3.9 | 0.0 | 0.6 | 0.1 | 0.7 |
| Sweden | Baltics | 2.7 | 0.2 | 1.1 | 3.9 | 0.0 | 0.6 | 0.1 | 0.7 |
| **Sum** | | **31.0** | **1.0** | **8.6** | **40.5** | **0.2** | **7.0** | **1.1** | **8.2** |

**Export to non-NordPool countries**

**Table 6.7: Average annual export to non-NordPool countries, (TWh/year)**

| Exporting country | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 5.5 | 3.8 | 9.3 | 6.6 | 5.1 | 11.7 | 6.3 | 5.5 | 11.7 |
| Sweden | 5.9 | 3.0 | 8.9 | 6.9 | 4.6 | 11.5 | 6.7 | 4.9 | 11.6 |
| Finland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Denmark | 8.6 | 5.2 | 13.8 | 9.8 | 7.2 | 17.0 | 9.6 | 7.6 | 17.2 |
| **Sum** | **20.0** | **12.0** | **32.0** | **23.3** | **16.9** | **40.2** | **22.5** | **18.0** | **40.5** |

**Table 6.8: Absolute change in export to non-NordPool countries compared to reference case (TWh/year)**

| Exporting country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 1.1 | 1.3 | 2.4 | 0.8 | 1.7 | 2.4 |
| Sweden | 1.0 | 1.6 | 2.6 | 0.8 | 1.9 | 2.7 |
| Finland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Denmark | 1.2 | 2.0 | 3.2 | 1.0 | 2.4 | 3.4 |
| **Sum** | **3.3** | **4.9** | **8.2** | **2.5** | **6.0** | **8.5** |

**Table 6.9: Relative change in export to non-NordPool countries compared to reference case (%)**

| Exporting country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 20.0 | 34.2 | 25.8 | 14.5 | 44.7 | 25.8 |
| Sweden | 16.9 | 53.3 | 29.2 | 13.6 | 63.3 | 30.3 |
| Finland | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Denmark | 14.0 | 38.5 | 23.2 | 11.6 | 46.2 | 24.6 |
| **Sum** | **16.5** | **40.8** | **25.6** | **12.5** | **50.0** | **26.6** |

### Import from non-NordPool countries

**Table 6.10: Average annual import from non-NordPool countries (TWh/year)**

| Importing country | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 2.0 | 3.4 | 5.4 | 1.0 | 1.9 | 2.9 | 1.2 | 1.9 | 3.1 |
| Sweden | 1.0 | 3.2 | 4.1 | 0.5 | 1.8 | 2.3 | 0.6 | 1.6 | 2.2 |
| Finland | 5.5 | 5.0 | 10.5 | 5.5 | 5.0 | 10.5 | 4.8 | 5.7 | 10.5 |
| Denmark | 1.3 | 3.1 | 4.4 | 0.8 | 2.1 | 2.9 | 0.9 | 2.0 | 2.9 |
| **Sum** | **9.7** | **14.8** | **24.5** | **7.7** | **10.8** | **18.5** | **7.6** | **11.1** | **18.7** |

**Table 6.11: Absolute change in import from non-NordPool countries compared to reference case (TWh/year)**

| Importing country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -1.0 | -1.5 | -2.5 | -0.8 | -1.5 | -2.3 |
| Sweden | -0.5 | -1.4 | -1.8 | -0.4 | -1.6 | -1.9 |
| Finland | 0.0 | 0.0 | 0.0 | -0.7 | 0.7 | 0.0 |
| Denmark | -0.5 | -1.0 | -1.5 | -0.4 | -1.1 | -1.5 |
| **Sum** | **-2.0** | **-4.0** | **-6.0** | **-2.1** | **-3.7** | **-5.8** |

**Table 6.12: Relative change in import from non-NordPool countries compared to reference case (%)**

| Importing country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -50.0 | -44.1 | -46.3 | -40.0 | -44.1 | -42.6 |
| Sweden | -50.0 | -43.8 | -43.9 | -40.0 | -50.0 | -46.3 |
| Finland | 0.0 | 0.0 | 0.0 | -12.7 | 14.0 | 0.0 |
| Denmark | -38.5 | -32.3 | -34.1 | -30.8 | -35.5 | -34.1 |
| **Sum** | **-20.6** | **-27.0** | **-24.5** | **-21.6** | **-25.0** | **-23.7** |

**Export to other NordPool countries**

**Table 6.13: Average annual export to NordPool countries (TWh/year)**

| Exporting country | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 2.0 | 2.5 | 4.4 | 4.2 | 4.6 | 8.8 | 3.3 | 5.1 | 8.4 |
| Sweden | 18.0 | 13.2 | 31.1 | 20.4 | 13.9 | 34.2 | 20.0 | 14.0 | 34.0 |
| Finland | 0.6 | 0.2 | 0.8 | 0.5 | 0.1 | 0.6 | 0.3 | 0.1 | 0.4 |
| Denmark | 1.6 | 5.0 | 6.6 | 0.6 | 2.9 | 3.5 | 0.8 | 2.7 | 3.5 |
| **Sum** | **22.1** | **20.9** | **43.0** | **25.6** | **21.5** | **47.1** | 24.5 | 21.8 | 46.3 |

**Table 6.14: Absolute change in export to NordPool countries compared to reference case (TWh/year)**

| Exporting country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 2.2 | 2.1 | 4.4 | 1.3 | 2.6 | 4.0 |
| Sweden | 2.4 | 0.7 | 3.1 | 2.0 | 0.8 | 2.9 |
| Finland | -0.1 | -0.1 | -0.2 | -0.3 | -0.1 | -0.4 |
| Denmark | -1.0 | -2.1 | -3.1 | -0.8 | -2.3 | -3.1 |
| **Sum** | **3.5** | **0.6** | **4.1** | **2.4** | **0.9** | **3.3** |

**Table 6.15: Relative change in export to NordPool countries compared to reference case (%)**

| Exporting country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 110.0 | 84.0 | 100.0 | 65.0 | 104.0 | 90.9 |
| Sweden | 13.3 | 5.3 | 10.0 | 11.1 | 6.1 | 9.3 |
| Finland | -16.7 | -50.0 | -25.0 | -50.0 | -50.0 | -50.0 |
| Denmark | -62.5 | -42.0 | -47.0 | -50.0 | -46.0 | -47.0 |
| **Sum** | **15.8** | **2.9** | **9.5** | **10.9** | **4.3** | **7.7** |

**Import from other NordPool countries**

**Table 6.16: Average annual import from NordPool countries (TWh/year)**

| Importing country | Reference | | | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year | Summer | Winter | Year |
| Norway | 12.5 | 9.7 | 22.2 | 9.6 | 7.0 | 16.6 | 9.6 | 6.0 | 15.6 |
| Sweden | 2.0 | 4.6 | 6.6 | 2.4 | 4.3 | 6.7 | 1.7 | 4.2 | 6.0 |
| Finland | 2.8 | 4.5 | 7.3 | 4.1 | 5.5 | 9.6 | 4.5 | 5.9 | 10.5 |
| Denmark | 4.9 | 2.0 | 6.9 | 9.4 | 4.8 | 14.2 | 8.6 | 5.6 | 14.2 |
| **Sum** | **22.1** | **20.9** | **43.0** | **25.6** | **21.5** | **47.1** | **24.5** | **21.8** | **46.3** |

**Table 6.17: Absolute change in import from NordPool countries compared to reference case (TWh/year)**

| Importing country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -2.9 | -2.7 | -5.6 | -2.9 | -3.7 | -6.6 |
| Sweden | 0.4 | -0.3 | 0.1 | -0.3 | -0.4 | -0.6 |
| Finland | 1.3 | 1.0 | 2.3 | 1.7 | 1.4 | 3.2 |
| Denmark | 4.5 | 2.8 | 7.3 | 3.7 | 3.6 | 7.3 |
| **Sum** | **3.5** | **0.6** | **4.1** | **2.4** | **0.9** | **3.3** |

**Table 6.18: Relative change in import from NordPool countries compared to reference case (%)**

| Importing country | Echam | | | Hadam | | |
|---|---|---|---|---|---|---|
| | Summer | Winter | Year | Summer | Winter | Year |
| Norway | -23.2 | -27.8 | -25.2 | -23.2 | -38.1 | -29.7 |
| Sweden | 20.0 | -6.5 | 1.5 | -15.0 | -8.7 | -9.1 |
| Finland | 46.4 | 22.2 | 31.5 | 60.7 | 31.1 | 43.8 |
| Denmark | 91.8 | 140.0 | 105.8 | 75.5 | 180.0 | 105.8 |
| **Sum** | **15.8** | **2.9** | **9.5** | **10.9** | **4.3** | **7.7** |

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